SALT as an instrument tester: the experimental laser frequency comb

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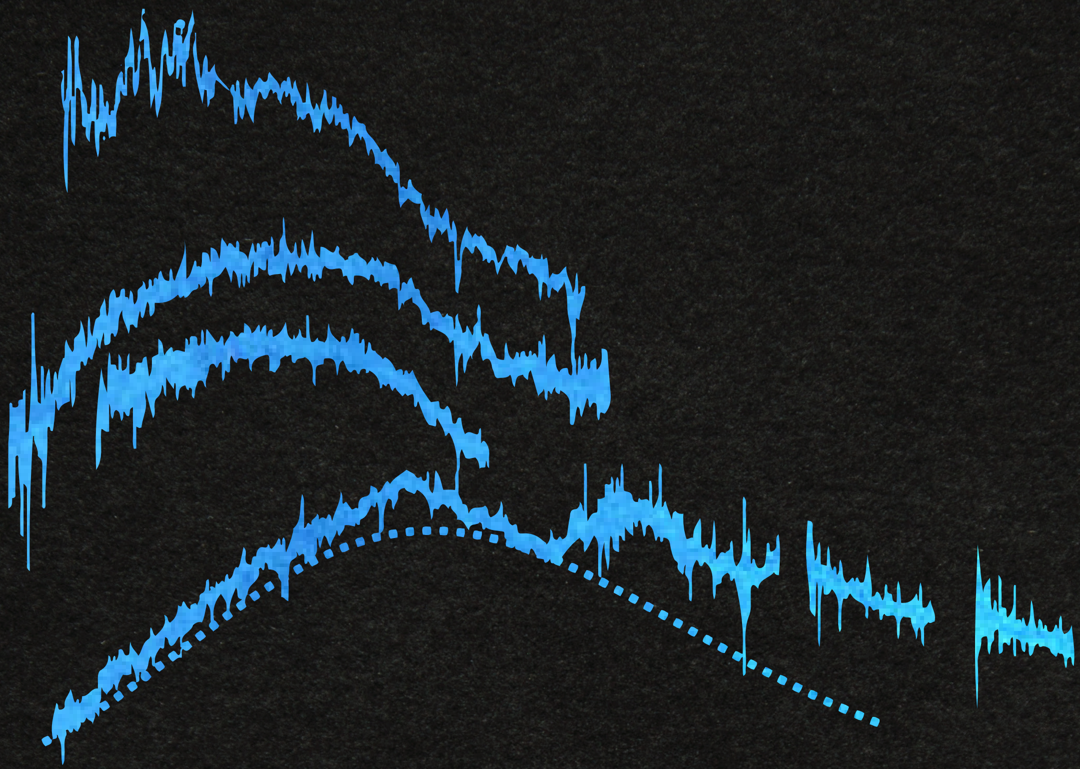


SOUTHERN AFRICAN LARGE TELESCOPE

ANNUAL REPORT 2017

BEGINNING OF A NEW ERA

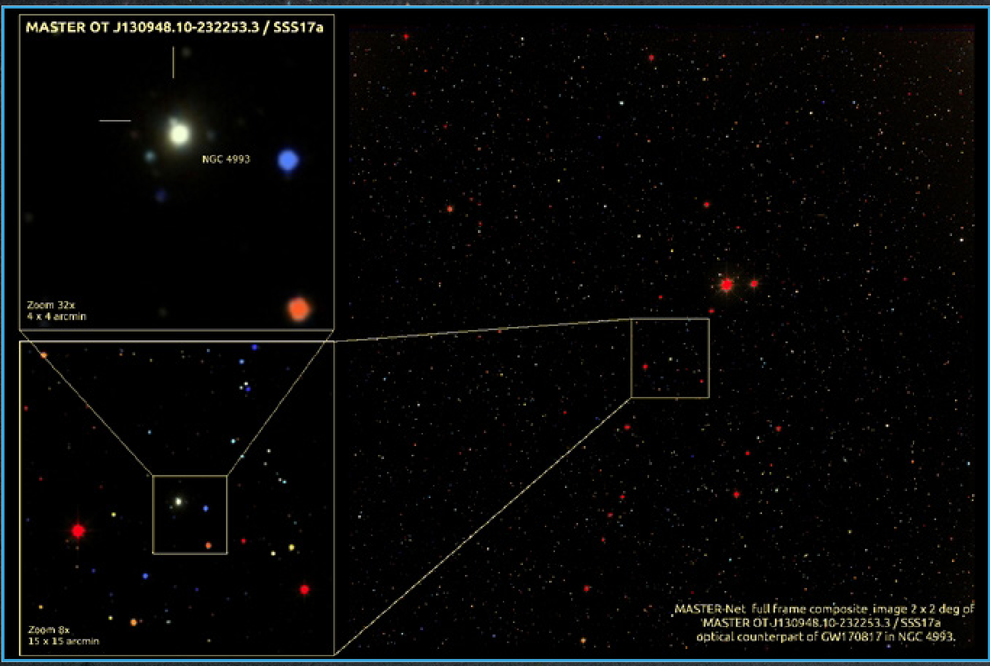
Multi-messenger events:
combining gravitational wave and electromagnetic astronomy

A NEW KIND OF SUPERSTAR: KILONOVAE – VIOLENT MERGERS OF NEUTRON STAR BINARIES

On 17 August 2017 the LIGO and Virgo gravitational wave observatories discovered their first candidate for the merger of a neutron star binary. The ensuing explosion, a kilonova, which was observed in the lenticular galaxy NGC 4993, is the first detected electromagnetic counterpart of a gravitational wave event.

One of the earliest optical spectra of the kilonova, AT 2017gfo, was taken using RSS on SALT. This spectrum was featured in the multi-messenger summary paper by the full team of 3677 collaborators. Combining this spectrum with another SALT spectrum, as well as spectra from the Las Cumbres Observatory network and Gemini–South, Curtis McCully from the Las Cumbres Observatory and his colleagues were able to follow the full evolution of the kilonova. The spectra evolved very rapidly, from blue (~6400K) to red (~3500K) over the three days they observed. The spectra are relatively featureless – some weak features exist in the latest spectrum, but they are likely due to the host galaxy.

However, a simple blackbody is not sufficient to explain the data: another source of luminosity or opacity is necessary. Predictions from simulations of kilonovae qualitatively match the observed spectroscopic evolution after two days past the merger, but underpredict the blue flux in the earliest spectrum from SALT. From the best-fit models, the team infers that AT 2017gfo had an ejecta mass of 0.03 solar masses, high ejecta velocities of 0.3c, and a low mass fraction ~0.0001 of high-opacity lanthanides and actinides. One possible explanation for the early excess of blue flux is that the outer ejecta is lanthanide-poor, while the inner ejecta has a higher abundance of high-opacity material.



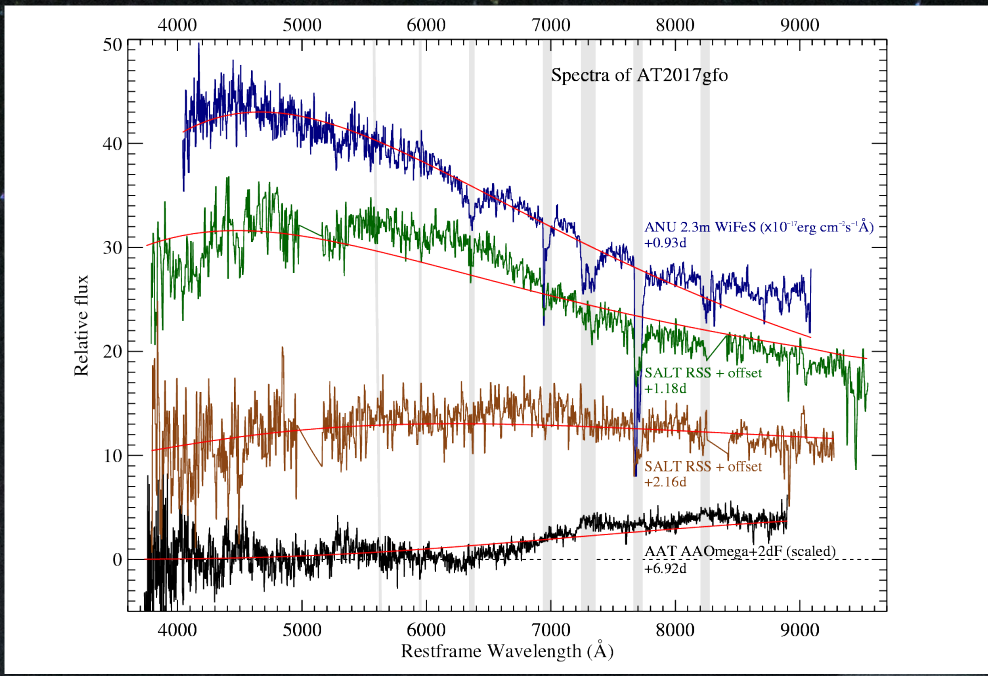
MASTER–Net full frame composite of GW170817. Filters used are B, R, I, and W; MASTER telescopes in South Africa and Argentinia were used. The kilonova position is marked by white lines on the left part of the composed image. The right (large) image is the MASTER main telescope's usual FOV.

Image credit: MASTER–Net/NRF/SAAO

Shara, M., et al. 2017, GCN 21610: LIGO/VIRGO G298048: SALT optical spectra of the candidate optical/NIR counterpart of the gravitational wave G298048 in NGC4993

Abbott, B.P., et al., 2017/10, ApJ Letters 848, 12L: Multi-messenger observations of a binary neutron star merger

McCully, C., et al., 2017/10, ApJ Letters 848, 32L: The rapid reddening and featureless optical spectra of the optical counterpart of GW170817, AT 2017gfo, during the first four days



Ph.D. student Igor Andreoni from Swinburne University of Technology and his collaborators studied the rapid spectral evolution of the electromagnetic counterpart AT2017gfo using the two SALT spectra together with spectra obtained at two Australian telescopes. Vertical grey bands denote telluric features that are not well removed in some spectra. Blackbody model fits (red curves) over the full spectra result in temperatures of 6 275 K (WiFeS), 6 475 and 4 700 K (RSS), and 2 080 K (AAOmega). Peaks in the WiFeS, RSS, and AAOmega continua correspond to ~6400 K, ~5600 K, ~4400 K, and <3200 K, respectively.

SALT CATCHES A GRAVITATIONAL WAVE

An otherwise normal Friday, the 18th August 2017 quickly became an exciting day at SALT. An urgent phone call around midday from Mike Shara alerted the team about a possible electromagnetic counterpart to a gravitational wave detection. The TechOps team rushed to prepare the telescope for observations that night while Petri Väisänen, the SALT Astronomer on duty, waited for details about the target. As it turned out, he would only have a small window during early twilight to catch observations of the transient object in NGC 4993, some 130 million light-years away.

With support from Cape Town, including Encarni Romero Colmenero, Steve Potter, Ted Williams, and Steve Crawford, Petri obtained a low resolution spectrum of the kilonova that resulted from GW 170817, a merger of two neutron stars. The spectrum, obtained barely a day after the initial detection, was heavily contaminated by twilight and blended with the host galaxy. After careful extraction, the spectrum revealed the still hot fireball that resulted from the explosion.

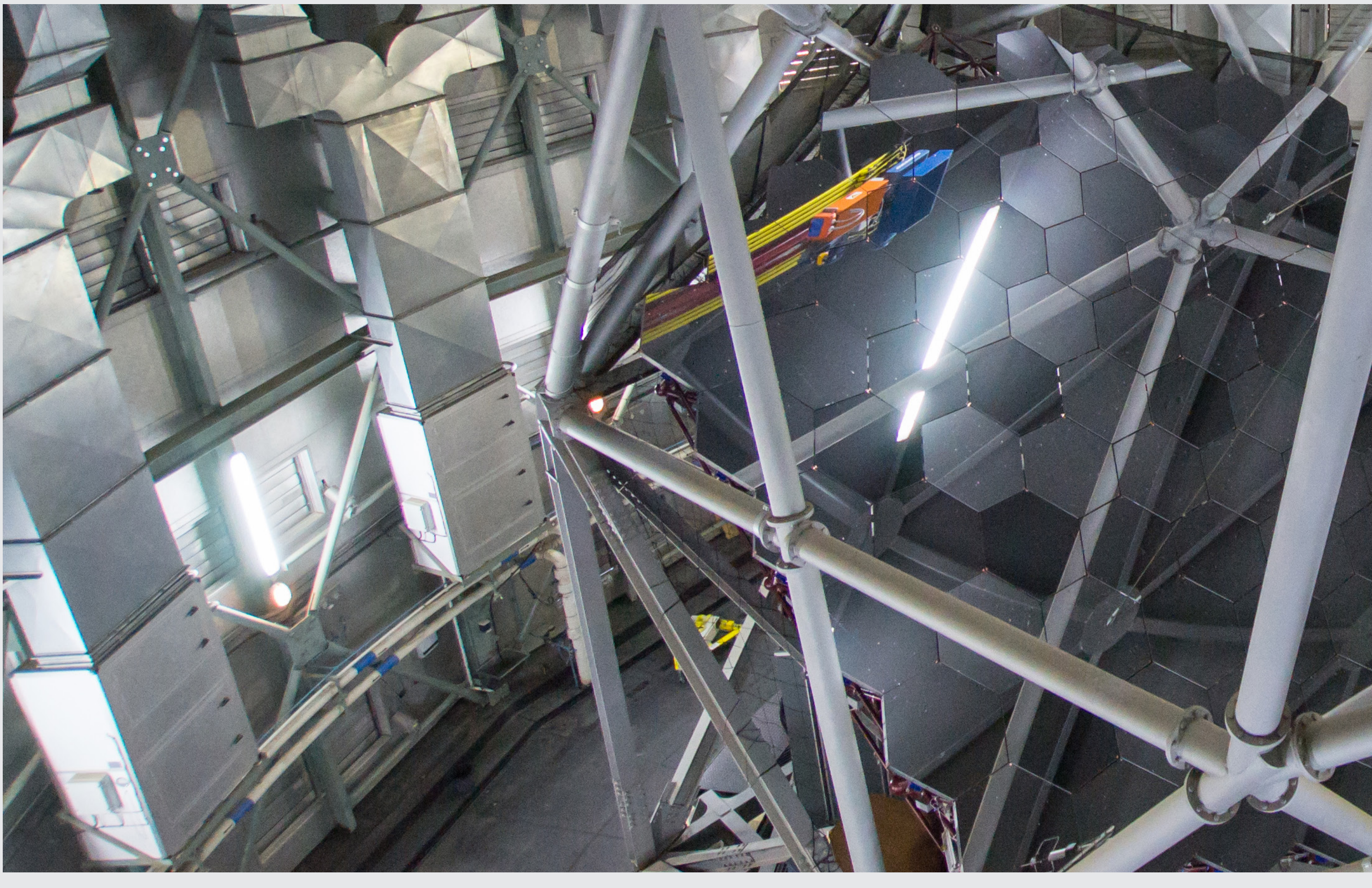
Spectra were attempted the following nights as well before the object completely disappeared from the SALT visibility window after 20th August. Combined with observations from other observatories, these data helped track how the kilonova rapidly cooled (McCully et al.). SALT was the third facility to obtain a spectrum of the event and provided important coverage between observations made in Australia and Chile (Valenti et al., Andreoni et al.). The SALT spectrum was highlighted in the multi-messenger paper (Abbott et al.) that announced the beginning of a new era of astrophysics that combines two different carriers of information: electromagnetic radiation and gravitational waves.

Front page image: Four early spectra: SALT (at t=1.2d), ESO–NTT and SOAR (at t=1.4d) and ESO–VLT (at 2.4d). Each spectrum is normalised to its maximum and shifted arbitrarily along the linear y–axis. The high background in the SALT spectrum below 4500Å prevents the identification of spectral features in this band (Abbott et al. 2017)

Valenti, S., et al., 2017/10, ApJ Letters 848, 24L: The discovery of the electromagnetic counterpart of GW170817: Kilonova AT 2017gfo/DLT17ck

Andreoni, I., et al., 2017/12, PASA 34, 69: Follow up of GW170817 and its electromagnetic counterpart by Australian-led observing programmes

Buckley, D.A.H., et al., 2018/02, MNRAS 474, 71L: A comparison between SALT/SAAO observations and kilonova models for AT 2017gfo: the first electromagnetic counterpart of a gravitational wave transient – GW170817

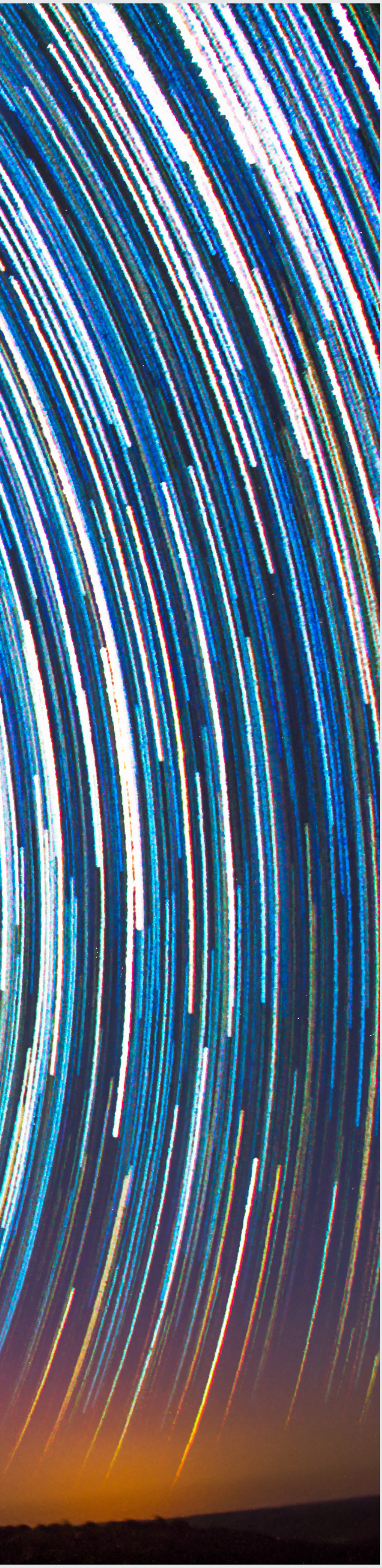


SOUTHERN AFRICAN LARGE TELESCOPE

PO Box 9, Observatory, 7935, South Africa

Phone: +27 (0)21 447 0025

Email: salt@salt.ac.za



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ABOUT SALT

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Like diamond dust on velvet, the myriad stars of the Milky Way are strewn across the evening sky with the Magellanic Clouds gleaming below. The last glow of sunset is fading behind the SALT dome as the astronomers get ready to reap their nightly harvest of answers to the equally myriad questions of science.

The Board of the Southern African Large Telescope (SALT) is proud to present its Annual Performance Report for the period 1st January 2017 to 31st December 2017. This report offers an overview of the activities and performance of SALT, highlights a selection of SALT research projects, and introduces the SALT partner institutions/consortia.

SALT is the largest single optical telescope in the southern hemisphere and amongst the largest in the world. It has a hexagonal primary mirror array 11 meters in diameter, consisting of 91 individual 1-m hexagonal mirrors. It is the non-identical twin of the Hobby–Eberly Telescope (HET) located at McDonald Observatory in West Texas (USA). The light gathered by SALT's huge mirror is fed into a suite of instruments (an imager and two spectrographs) from which astronomers infer the properties of planets, stars and galaxies, as well as the structure of the Universe itself.

SALT is owned by the SALT Foundation, a private company registered in South Africa. The shareholders of this company include universities, institutions and science funding agencies from Africa, India, Europe and North America. The South African National Research Foundation is the major shareholder with a ~35 percent stake. Other large shareholders are the University of Wisconsin–Madison, Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences, Dartmouth College and Rutgers University. Smaller shareholders include the American Museum of Natural History, the Indian Inter–University Centre for Astronomy and Astrophysics in India, the University of North Carolina and the UK SALT Consortium, the latter representing the Universities of Central Lancashire, Keele, Nottingham and Southampton, the Open University and the Armagh Observatory. The size of the shareholding of each partner determines the access to the telescope that they enjoy. The HET Consortium, although not a shareholder, received ten percent of the telescope time for the first ten years of operation, in return for providing all the designs and plans of the HET as well as assistance during the construction of SALT. Two of the original shareholders, the University of Canterbury (New Zealand) and Göttingen University (Germany), have recently left the SALT Foundation but still received telescope time in 2017. The SALT Foundation is currently looking for new shareholders.

SALT is located at the observing site of the South African Astronomical Observatory, near the small Karoo town of Sutherland, about 380 km north-east of Cape Town. This site has been host to a number of other smaller telescopes since the early 1970s, and benefits from location in a semi-desert region with clear, dark skies. The quality of this site for optical astronomy is preserved by South African legislation.

VISION & MISSION

VISION

Africa's Giant Eye on the Sky: Inspiring society by exploring the Universe.

MISSION

Lead the advancement and development of optical astronomy on the African continent and inspire and educate new generations of scientists and engineers worldwide.

Provide a world-class large telescope research facility cost-effectively to astronomers in an international community.

STRATEGIC OBJECTIVES OF SALT

1 Enable world-leading astrophysical research

To provide high-quality data that result in highly-cited papers published in front-rank journals. This is achieved by maximising SALT's scientific productivity, i.e., minimising technical downtime and optimising operational efficiency. Which is contingent on having the financial resources to support operational needs and to nurture and retain a cohort of skilled and creative staff, and enabling them to identify and pursue key scientific and technical initiatives.

2 Pursue instrumentation development

To establish the local skills and capacity required to design and build internationally competitive astronomical instrumentation. This calls for leveraging expertise available within the SALT partnership and other international instrumentation groups, to build active collaborations that drive technological innovation and skills transfer, and ultimately enhance SALT's capabilities. This, too, relies on securing the necessary financial support, for both equipment and people (staff, students, interns and apprentices spanning a broad range of levels).

3 Drive human capital development and science engagement

To employ this iconic facility and the ubiquitous appeal of astronomy to encourage widespread interest in science and technology, through outreach to undergraduates, schools and the general public; to train graduate-students; to have a special focus on developing and leading professional astronomy and high-tech astronomical instrumentation on the African continent; to promote SALT as a global flagship optical telescope, increasing its visibility and growing its reputation in the international scientific community, as well as national and international media.

CHAIRMAN'S OVERVIEW

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"The Five-Year-Review of all aspects of SALT done in 2016 generated a series of strong and extremely useful recommendations which were studied by the SALT Board, and which were published in 2017 with the Board's responses. Most of the review's recommendations were accepted; their implementation is underway."

SALT continues to generate large amounts of excellent science data every clear night, and 2017 has been the most productive year yet for the telescope. A record number of observations were taken, with data reduced and sent to observers the following day. The telescope is operationally stable, and in excellent mechanical, optical, electronic and software shape. The first generation instruments – SALTICAM, RSS and the HRS – are exhibiting high throughput and functioning as designed. The ongoing hard work of the engineering and software support teams has made this possible.

Nearly 50 peer-reviewed SALT science papers (an all-time high) were published during 2017, including two SALT Nature papers (Shara et al., 31 August 2017 and Jiang et al., 05 October 2017). SALT obtained one of the first spectra of the merging binary neutron stars GW170817, and this spectrum was a prominent part of the Astrophysical Journal Letter multi-messenger discovery paper (Abbott et al., 20 October 2017).

The HRS data pipeline has been extensively tested, and is now fully functional. Several years of backlogged HRS data have been processed through it, and delivered to PIs. All raw and fully-processed data taken with HRS are now delivered within 24 hours.

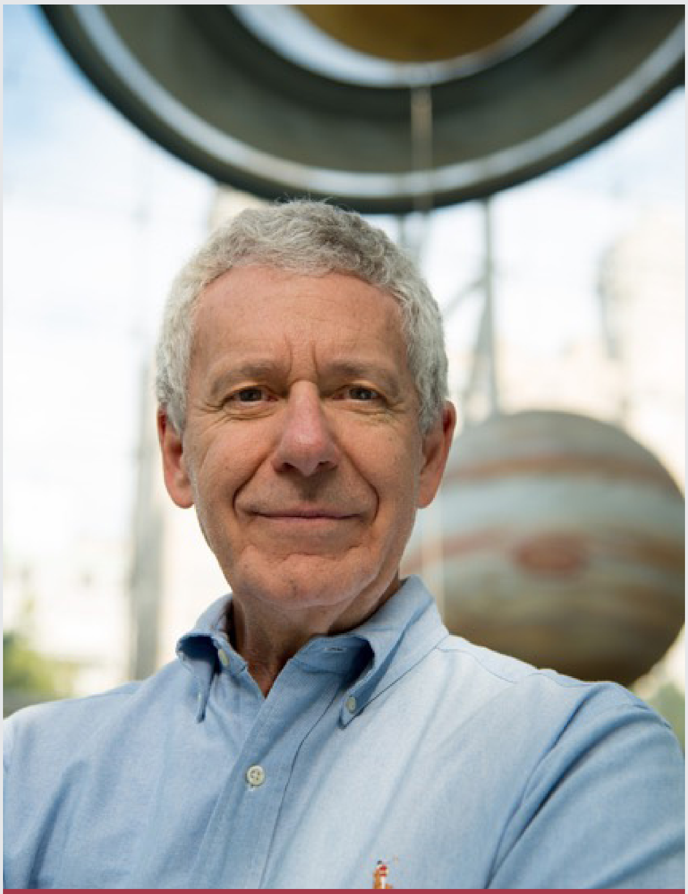
The edge-sensor system (SAMS), which keeps the 91 SALT mirror segments aligned, continues to perform at spec or better, saving 1–2 hours every night that used to be spent on alignments.

The next instrument to be delivered – a near-infrared spectropgraph – is currently scheduled to arrive in mid 2019. Town hall meetings were held in South Africa about next generation instruments, to follow the NIR spectropgraph. Based on those discussions, and a science strategy adopted by the SALT Board, three possible instruments and upgrades have been identified. The science capabilities most desired by the SALT community in the SKA/LSST era have been the key drivers in designating the desired new capabilities and instruments. Engineering studies are underway or planned to determine costs and capabilities for these three options. The Five-Year-Review of all aspects of SALT done in 2016 generated a series of strong and extremely useful recommendations which were studied by the SALT Board, and which were published in 2017 with the Board's responses. Most of the review's recommendations were accepted; their implementation is underway.

SALT's operations budget is only a fraction of that of other 8 to 10–meter telescopes. This is, in part, due to lower wages in South Africa than in, say, Hawaii, Chile or Spain. It is also due to the discipline of the CFO and Director, and the determination of the Board to keep to a lean budget.

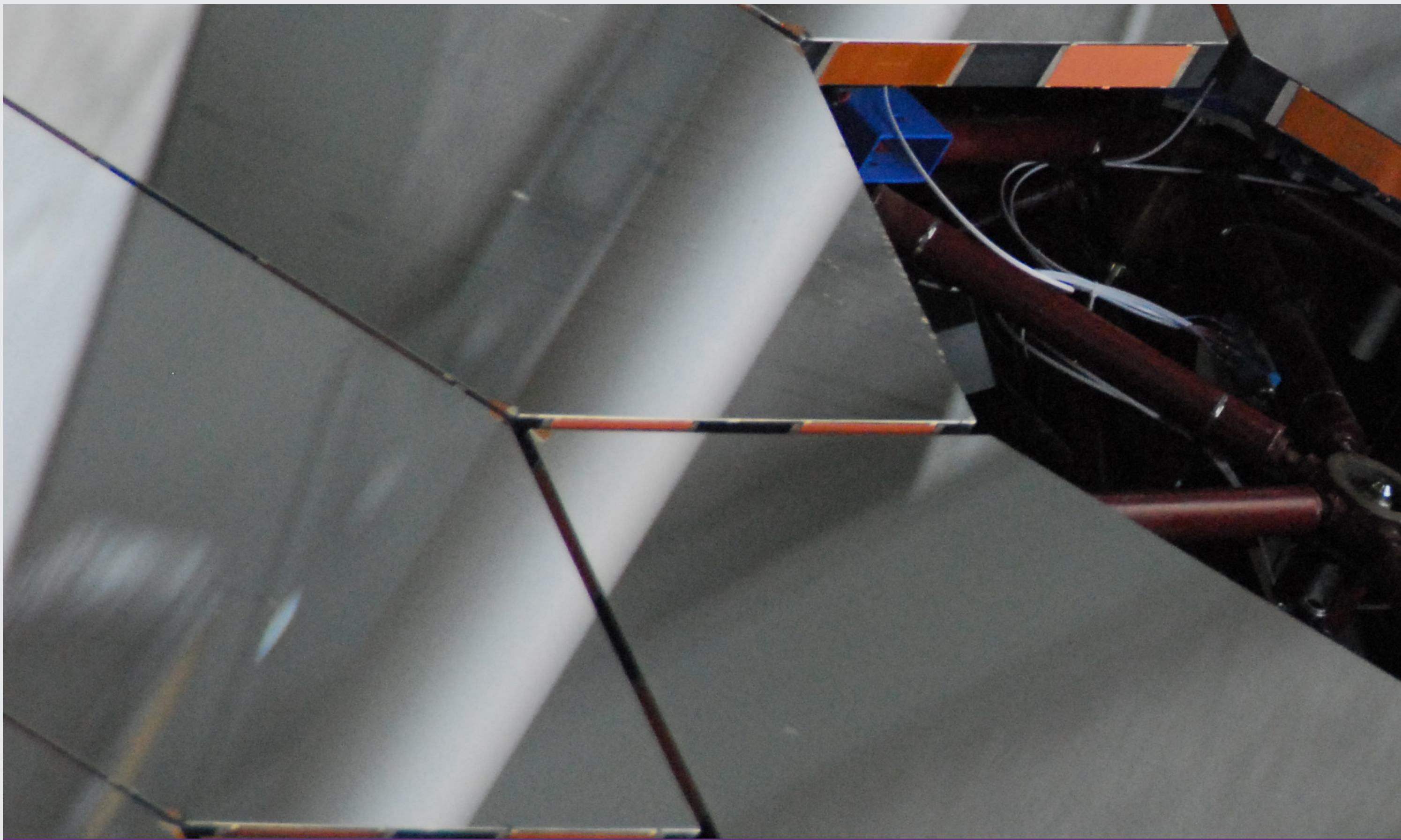
During 2017, 90% of the Board's Development Fund target was received from the SALT partners. This has contributed to the strongest financial position of SALT in the past decade. With the telescope and its instruments now in excellent condition, the Board continues to search for a new partner interested in purchasing 10% of the shares in, and observing time on SALT.

Prof. Michael Shara
Chairperson, SALT Board



Prof. Michael Shara

SALT PARTNERS: AN INTRODUCTION



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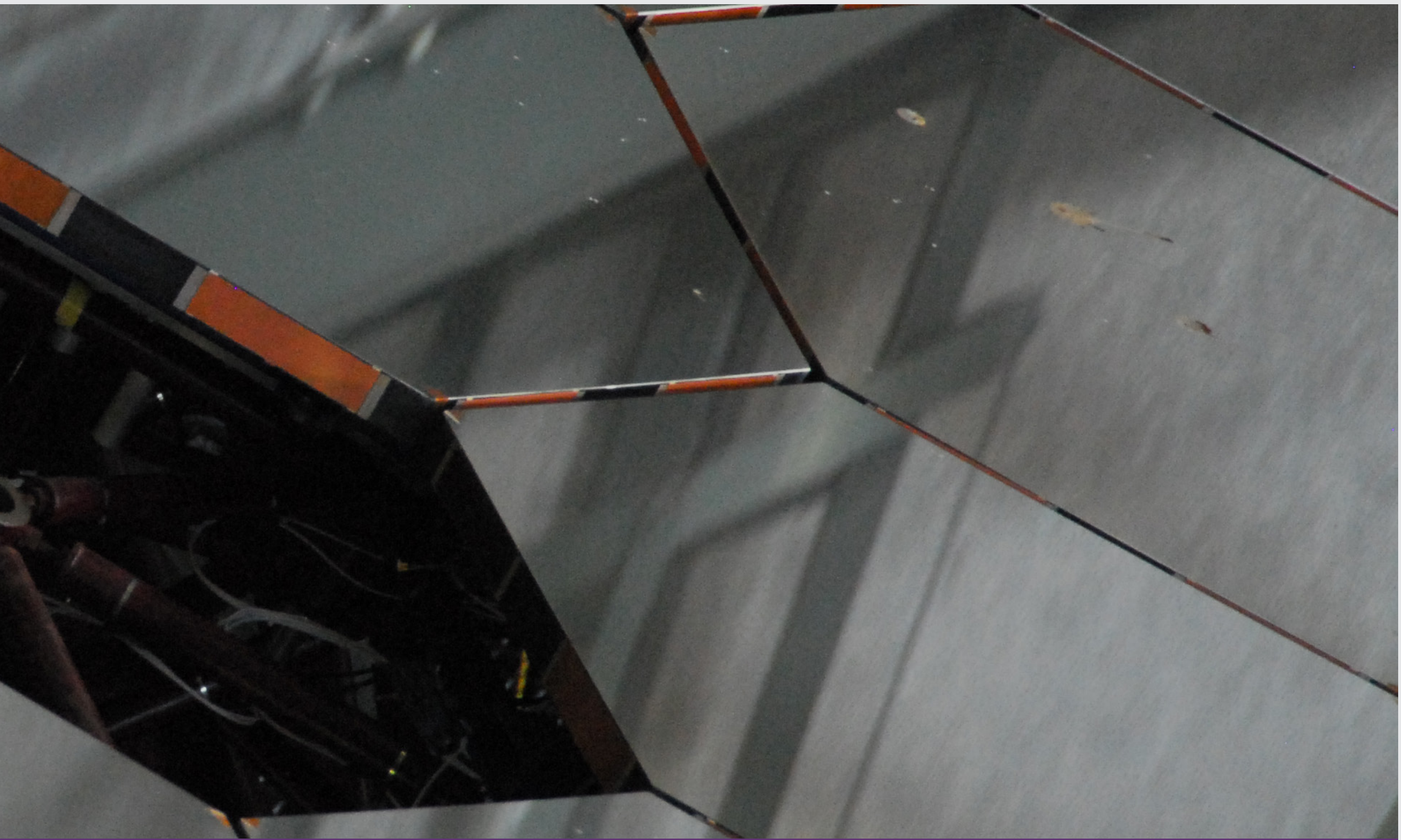


INTRODUCING: OUR SALT PARTNERS

SALT is an international consortium consisting of a small number of partners that share the costs of the telescope, in return for corresponding fractions of the available observing time. Some of the partners have also made in-kind contributions, in the form of instruments and/or other intellectual property, to secure their membership. Each partner country or institution has their own time allocation committee and scientists outside the consortium that wish to use SALT are welcome to collaborate with those affiliated with partner institutions. SALT also offers a limited amount of free Director's Discretionary Time* (DDT) for the opportunistic pursuit of high-impact science, as the flexibility of SALT's queue-scheduled operation supports rapid response to new top-priority targets.

The SALT Foundation now also invites researchers from around the world to purchase their own guaranteed SALT time. This can be in the form of normal time divided into the default priority categories ("P0" to "P3"), to be inserted in the service observing (at a rate of ~27,500 ZAR/h). It may also be in the form of the highest priority time only, which is guaranteed to be observed fully, at twice that rate. Note that any partner institution may also purchase time beyond their normal share, and reduced rates apply in that case. Finally, the consortium is seeking an additional 10%–level partner (~$8.8M) to support significant second-generation instrumentation development. Interested parties should contact the chair of the SALT Board of Directors, Michael Shara.

*http://astronomers.salt.ac.za/proposals/directors-discretionary-time/

REPUBLIC OF SOUTH AFRICA

South Africa's National Research Foundation (NRF) is the majority shareholder in SALT, with approximately a one-third share. The South African Astronomical Observatory (SAAO), contracted to host and operate SALT, is also one of the NRF's several national facilities. As the intermediary agency between the policies and strategies of the government of South Africa and the country's research institutions, the NRF's mandate is to promote and support research through funding, human resource development and the provision of the necessary facilities, in order to facilitate the creation of knowledge, innovation and development in all fields of science and technology (including indigenous knowledge), and to thereby contribute to improving the quality of life of all South Africans. The country's considerable investment in astronomy, both in optical and radio, is due in no small part to this field's extraordinary potential to capture the imagination and hence to encourage the brightest young minds to pursue scientific and technical qualifications.

SALT is located at the Sutherland site of SAAO in the Karoo desert (about 400 km from Cape Town), making it one of the darkest sites in the world. SAAO hosts all the SALT Astronomers, responsible for liaising with PIs and making the observations, as well as all the technical and support staff associated with SALT. The Observatory's mechanical and electronic departments at SAAO's headquarters in Cape Town include large workshops and a dedicated CCD lab. SALTICAM and the RSS detector package as well as the fibre-instrument feed and various auto-guiders for the SALT instruments were designed and built here. The maintenance and servicing of all instruments and telescope sub-systems is done in Sutherland by the technical operations team.

One of SALT's strategic objectives is Human Capital Development which is particularly important for South Africa and, even more so, for the African continent. Thus the SALT Collateral Benefits Programme (SCBP) was established during the construction of SALT and objectives of this programme were clearly directed at the benefits derived by society from building this large telescope. The SCBP is mainly directed at schools but also includes outreach to the general public.

South Africa's astronomical community has grown significantly since SALT was built, with SALT and later the SKA/MeerKAT initiatives spurring much of this growth. There are now about two hundred Ph.D. astronomers at institutes around the country and students at all levels of study. Students are actively encouraged to participate in SALT projects and to propose for time on SALT. Scientists from national research facilities and universities across the country use SALT regularly. These include, but are not limited to, the Universities of Johannesburg, Witwatersrand, the Free State, Cape Town), the Western Cape, the North West, KwaZulu Natal and, primarily, SAAO. The entire South African community has access to SALT via a very competitive process in which proposals to use SALT are peer-reviewed, scientifically ranked and awarded time through the efforts of the South African SALT Time Allocation Committee (SASTAC).

South African researchers are active across a wide range of the multi-wavelength astronomy domain. One of the largest SALT projects, led by David Buckley from SAAO, focuses on transient objects, with rapid follow-up triggered by alerts from other telescopes at SAAO and around the world. A number of different astronomical phenomena, both within and beyond the Milky Way, are explored through this programme. Galactic research makes heavy use of the HRS to explore a variety of interesting stars, planetary nebulae, binary systems and exoplanet hosts. Extragalactic research explores galaxy and galaxy cluster evolution by obtaining the redshifts, properties, kinematics and star formation histories of nearby and distant galaxies, including AGN research. The strategic vision for SALT, developed by the South African community in 2017, identified two main focus areas for future development which tie in closely with both MeerKAT, the country's precursor to the SKA, and local high-energy astrophysics research. These are transient science, a range of highly energetic phenomena (including exciting events such as the recent multi-messenger gravitational wave discovery) and galaxy evolution, particularly understanding the fuelling of star formation and recycling of gas in the baryon cycle. Exoplanet research and building instrumentation capacity have also been highlighted as growth points for the future.

SALT Board members:
Molapo Qhobela, National Research Foundation
Lisa Crause, SAAO/SALT

UNIVERSITY OF WISCONSIN–MADISON (USA)

The University of Wisconsin–Madison is a public, land-grant institution that offers a complete spectrum of studies through 13 schools and colleges. With more than 43,000 students from every U.S. state and 121 countries, UW–Madison is the flagship campus of Wisconsin's state university system.

UW–Madison is a formidable research engine, ranking sixth among U.S. universities as measured by dollars spent on research. Faculty, staff, and students are motivated by a tradition known as the Wisconsin Idea that the boundaries of the university are the boundaries of the state and beyond.

One of two doctorate-granting universities in the University of Wisconsin system, UW–Madison has the specific mission of providing "a learning environment in which faculty, staff and students can discover, examine critically, preserve and transmit the knowledge, wisdom and values that will help insure the survival of this and future generations and improve the quality of life for all."

UW–Madison joined the SALT partnership, contributing both to the construction as well as designing and building the Prime Focus Imaging Spectrograph, since renamed the Robert Stobie Spectrograph.

Wisconsin is now building a near-infrared spectrograph for SALT in its Washburn Laboratory. Wisconsin astronomers use SALT to understand the kinematics and distribution of ionized gas in and around galaxies, redshift surveys to measure the distribution of mass in galaxy clusters, surveys of galaxies at intermediate and high redshifts, as well as high-resolution studies of stellar variability.

SALT Board member: Eric Wilcots

The astronomy department group on top of their building.

RUTGERS UNIVERSITY (USA)

Rutgers, the State University of New Jersey, is a large public research university in the United States. Originally chartered as Queen's College in 1766 during the colonial era, in 1825 it was renamed Rutgers College after a wealthy benefactor. Rutgers became the New Jersey land-grant institution in 1864 and then in the mid–20th century it was designated the State University of New Jersey by the state legislature. The most recent major expansion to Rutgers was the addition of a medical school in 2012. Rutgers University has expanded far beyond its modest colonial roots. It now includes campuses in Newark and Camden as well as the flagship campus in New Brunswick. Across the state more than 8000 Rutgers faculty instruct over 49,000 undergraduate as well as 19,000 graduate students. There are more than 150 undergraduate majors and 200 graduate programs.

Astronomy was part of the curriculum at Rutgers since its earliest days. The current Department of Physics and Astronomy at Rutgers–New Brunswick traces its origins to the late 19th century. Significant expansion in the astronomy program began in the 1990's with the addition of a number of research-active astronomers and an increase in the number of graduate students. At the end of the decade Rutgers joined the SALT consortium. Today the astronomy group includes ten faculty, two research scientists, three postdoctoral associates, and 19 graduate students.

Rutgers' astronomers, led by Prof. Ted Williams, participated in the design, development and fabrication of the Robert Stobie Spectrograph (RSS) and led the effort to build the Fabry–Pérot Imaging Spectrophotometer subsystem. Williams, former professor Jerry Sellwood and their colleagues utilized this instrument to carry out the RSS Imaging spectroscopy Nearby Galaxies Survey (RINGS) of nearby, normal galaxies to characterize their structure using measurements of Hα velocity fields. Rutgers graduate student Carl Mitchell was awarded a Ph.D. degree in 2017 based on his analysis and interpretation of RINGS Fabry–Pérot data.

Prof. Saurabh Jha uses SALT to study supernova explosions, observing mostly Type Ia, or thermonuclear, supernovae with RSS to investigate their nature and, more broadly, to answer key questions in SN Ia cosmology. Former graduate students Curtis McCully and Brandon Patel worked with Jha on their Ph.D. thesis research on supernovae. Current students Yssavo Camacho and Kyle Dettman are working on several RSS supernova projects. Recently Jha started a new project to measure binary orbital parameters of a sample of candidate white dwarf binaries with the HRS.

A main area of Prof. John P. Hughes' research focuses on the astrophysics of supernova remnants. Determining how high speed shocks in remnants heat interstellar gas was the focus of former graduate student Luke Hovey's Ph.D. thesis awarded in 2016. Current student Prasiddha Arunachalam is using coronal iron line emission from RSS observations to study ejecta properties in the full sample of known SN Ia remnants in the Large Magellanic Cloud. In other research Hughes, in collaboration with colleagues in South Africa, has made dynamical mass measurements of galaxy clusters from the ground-based Atacama Cosmology Telescope to aid in precise cluster mass calibration for constraining cosmological parameters. He has also used SALT for confirmation and redshift measurement of Planck cluster candidates.

Prof. Andrew Baker is involved in two large SALT collaborations: the "SALT Gravitational Lensing Legacy Survey" and "Preparing for LADUMA: SALT Redshift Measurements". The former project targets submm-band sources from the Herschel space mission that are likely high-redshift ($z \sim 2-4$) gravitationally-lensed star forming galaxies. The goal is to obtain SALT spectroscopic redshifts of the nearby lensing galaxy to confirm a large sample (>100) of lensed systems. Baker is a Co–PI, along with South African and European colleagues S. Blythe and B. Holwerda, of the "Looking At the Distant Universe with the MeerKAT Array" (LADUMA) radio survey, which aims to study the evolution of neutral gas in galaxies over cosmic time. The SALT project, which Baker leads, uses RSS for redshift determination of galaxies in the LADUMA observing field with a goal of collecting 250 redshifts at $0.4 < z < 0.5$ to allow for determination of the mean H I gas fraction at these redshifts by co-adding MeerKAT H I spectra. In other related work, Baker's current graduate student John Wu is studying star formation in massive galaxy clusters using the RSS Fabry–Pérot instrument.

SALT Board member: Jack Hughes

The Physics & Astronomy department building at Rutgers–New Brunswick.

POLAND

Poland is a country with a long astronomical tradition: consider, for example, Nicolaus Copernicus (1473–1543) with his great work on the heliocentric system or Johannes Hevelius (1611–1687), author of Selenographia and inventor of several constellation names. From the end of the 18th century, however, Poland entered a dark period of its history. The Polish state disappeared from the map of Europe for about 120 years and wars swept the Polish soil during every generation. The last one, World War II, left Poland ruined, with devastated intelligentsia and no scientific resources. A few professional astronomers who survived the war, started to build scientific centers in some cities, literally from nothing. Currently, about 250 astronomers are employed in six separate university institutes and two institutes of the Polish Academy of Sciences. A few individual astronomers hold positions in other institutions, mostly within institutes of physics. The most important astronomical institutions in Poland are the Nicolaus Copernicus Astronomical Center, the Warsaw University Observatory and the Space Research of Polish Academy of Sciences with its three divisions located in Warsaw, Poznań and Wrocław.

Polish astronomers from various institutions are participating in the SALT project, with Poland having a 10% share in the construction and running costs. The Nicolaus Copernicus Astronomical Center (CAMK) is the Polish coordinator for the project. Marek J. Sarna of CAMK is Poland's Board director, and he has been highly active in the Board and other SALT committees. Janusz Kaluzny was the SSWG member until March 2015 and Joanna Mikołajewska is the current SSWG member, being highly involved in this and other SALT committees. In 2017, CAMK hosted the SALT Board meeting held 5–6 June in Kazimierz Dolny. The meeting was followed by a 3-day (7–9 June) workshop on "SALT among the constellations of very large telescopes" that was organized by the Polish SALT Foundation and CAMK. The main SALT partner institutions in Poland include:

Nicolaus Copernicus Astronomical Center

The Nicolaus Copernicus Astronomical Center (CAMK, or NCAC in English) of the Polish Academy of Sciences is the leading astronomical institute in Poland. It is located in Warsaw and was established in 1978. At present 57 scientists are working at CAMK along with 35 Ph.D. students. Most of the latter win attractive post-doctoral positions in the best institutes all over the world. Many return to Poland and successfully compete for positions at CAMK or elsewhere in Poland. Every summer CAMK invites physics and astronomy students for a summer training program where they work under supervision of CAMK scientists.

Astronomers at CAMK are involved in a number of major international observational projects (e.g., CTA, Herschel, SALT), and are actively collaborating with scientists at institutes, observatories and universities all over the world. Collaborations on SALT science include SAAO and the American Museum of Natural History. The main SALT research interests are: the search for symbiotic stars in the Milky Way and Magellanic Clouds and the study of

individual systems; novae; post AGB binaries and dark matter studies using spectroscopic long term monitoring of selected quasars.

Astronomical Observatory of the Jagiellonian University

The Observatory is a part of the Faculty of Physics, Astronomy and Applied Computer Science of the Jagiellonian University. The Observatory was founded in 1792 and comprises a number of small radio and optical telescopes that are located at Fort Skała at the outskirts of Kraków. The Observatory is involved in exploiting large facilities such as H.E.S.S., CTA, LOFAR and SALT. The main scientific programs that use SALT data are studies of accretion discs in AGNs using Doppler tomography and large galaxies.

Center for Astronomy of Nicolaus Copernicus University

The Center for Astronomy of the Nicolaus Copernicus University in Toruń is located in Piwnice village, 15 km north of Toruń, and is home to a 32-m radio telescope (a VLBI station) and a few optical instruments, among them a 90-cm Schmidt–Cassegrain telescope and a 60-cm photometric telescope. The optical telescopes are used mainly for student training and modest research projects. SALT researchers here are interested in symbiotic stars and novae as well as planetary nebulae.

Institute Astronomical Observatory of Adam Mickiewicz University

The history of the Astronomical Observatory of the Adam Mickiewicz University in Poznań dates back to 1906. Today it houses three main telescopes and several small ones for educational purposes. Research topics include the dynamics of artificial satellites and small bodies in the Solar system, including non-gravity effects, as well as the investigation of the physical properties of asteroids for which SALT observations have been obtained.

Astronomical Institute of Wrocław University

The Astronomical Institute of the Wrocław University is located in the eastern part of Wrocław. Research concentrates on two main subjects: investigation of solar activity and pulsating stars (using astroseismology). Observations are conducted with a coronagraph located near Wrocław and with SALT (among others), respectively. Satellite observations play an important role in these investigations as well.

SALT Board member: Marek Sarna, CAMK

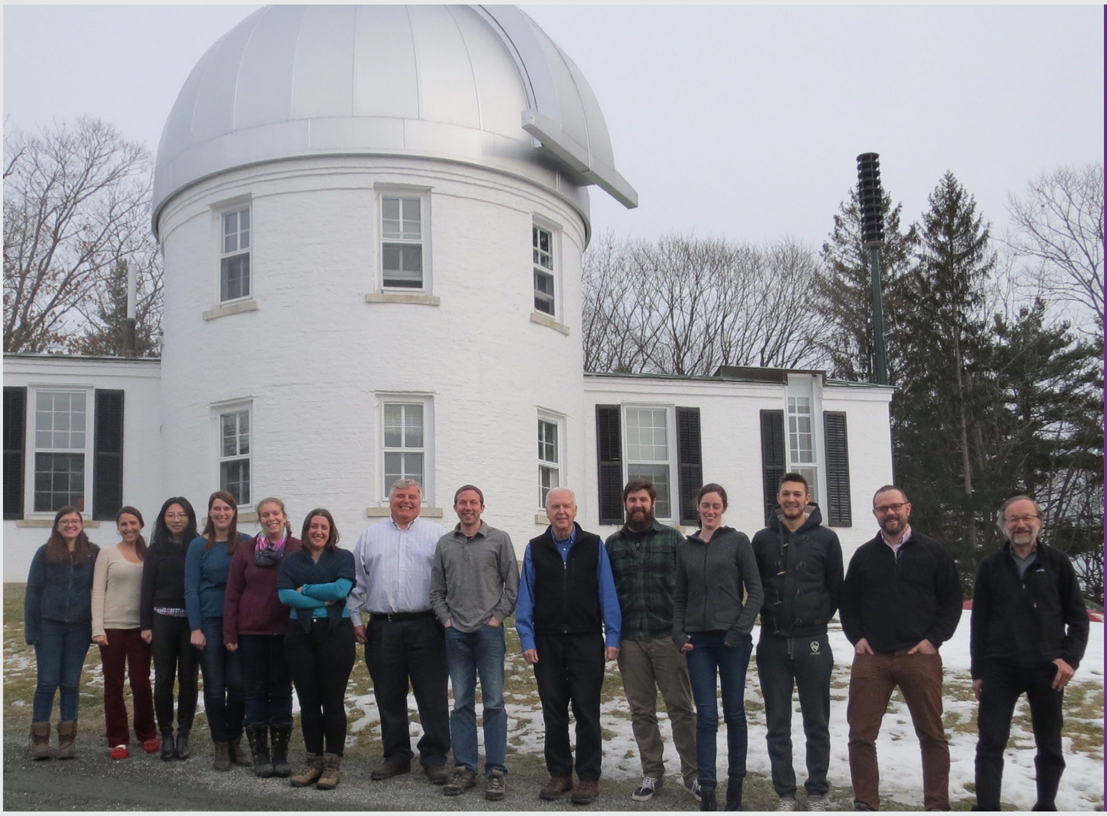
DARTMOUTH COLLEGE (USA)

Founded in 1769, Dartmouth College is one of the leading liberal arts universities in the United States. Dartmouth has forged a singular identity for combining its deep commitment to outstanding undergraduate liberal arts and graduate education with distinguished research and scholarship in the Arts & Sciences, and its three leading professional schools the Geisel School of Medicine, the Thayer School of Engineering, and the Tuck School of Business. Dartmouth College educates the most promising students (approximately 4300 undergraduates and 2000 graduate students) and prepares them for a lifetime of learning and of responsible leadership, through a faculty dedicated to teaching and the creation of knowledge.

Astronomy has a long history at Dartmouth, with the Shattuck Observatory (built in 1853) being the oldest scientific building on campus. The first photograph of a solar prominence was obtained by the Shattuck Observatory (in 1870).

Today, the astronomy group at Dartmouth is housed within the Department of Physics and Astronomy, and has a 25% share in MDM observatory (consisting of a 2.4-m and 1.3-m telescope in Kitt Peak, Arizona, USA) in addition to its ~10% investment in SALT. Astronomers at Dartmouth have a broad range of research interests, and have used SALT to study supernovae, active galactic nuclei and metal-poor stars, among other projects. Currently, the astronomy group consists of four faculty members, three post-doctoral fellows and about ten graduate students. We are currently recruiting new faculty members who are expected to be active in extragalactic astronomy or exoplanets.

SALT Board member: Brian Chaboyer



Astronomy group photo taken in front of the Shattuck Observatory on campus.

View of IUCAA's campus.

INTER–UNIVERSITY CENTRE FOR ASTRONOMY & ASTROPHYSICS (INDIA)

The Inter–University Centre for Astronomy & Astrophysics (IUCAA) was established in 1988 by the University Grants Commission of India in Pune. The main objectives of IUCAA are to provide a centre of excellence within the university sector for teaching, research and development in astronomy and astrophysics, as well as to promote nucleation and growth of active groups in these areas in colleges and universities. Besides conducting a vigorous research programme of its own, workers from Indian universities, teachers and students are enabled to visit IUCAA for any length of time to participate in research and to execute developmental projects. IUCAA also actively collaborates with universities in initiating and strengthening teaching and research in Astronomy & Astrophysics in the university system.

Research interests of IUCAA members and associates include (i) gravitation, cosmology, large scale structures in the universe, gravitational wave physics and data analysis; (ii) cosmic microwave background theory and data analysis, cosmic magnetic fields; (iii) galaxies, quasars, quasar absorption lines, intergalactic and interstellar matter; (iv) X-ray binaries, accretion disk theory, radio and X-ray pulsars, γ-ray bursts; (v) solar physics, stellar physics, stellar spectral libraries, machine learning; (vi) observations in optical, radio and X-ray bands, astronomical instrumentation and (viii) data driven astronomy, virtual observatory. IUCAA runs a 2-m telescope at Girawali to support various observational projects. Members of IUCAA are actively involved in various national large science projects such as the Indian participation in TMT, SKA and LIGO–INDIA etc., and IUCAA has a 7% share in SALT. It is utilised by IUCAA members to identify and study extra-galactic sources (large scale outflow, quasars, radio-galaxies and field galaxies producing absorption lines in quasar spectra), high-resolution spectroscopy of stars and coordinated observations of time-varying sources.

IUCAA's technical contribution to SALT is the SIDECAR Drive Electronics Controller (ISDEC) which is used as the control and data acquisition system for the H2RG detector in the new near-infrared spectrograph.

SALT Board member: Somak Raychaudhury

UK SALT CONSORTIUM

An early and enthusiastic supporter of the SALT project, the UK's consortium (UKSC) consists of 6 astronomy groups, all of whom have had a long-standing involvement with astronomers in South Africa (SA), including providing support for visiting graduate students and post-docs to SA. Furthermore, UKSC has successfully hosted a half-dozen SALT Stobie scholarships, greatly enhancing the production of South African astronomy Ph.D. This year the consortium was awarded "Global Challenges" research funding to support SA post-docs to visit the UK for extended periods. UKSC have a wide range of SALT science interests, and are involved as collaborators in a number of major SALT science projects that are described elsewhere in this report. Our science interests and activities are:

The photo was taken at the latest UKSC management committee meeting in Keele in November 2017.

1. University of Central Lancashire (Gordon Bromage, Anne Sansom, Don Kurtz, Dan Holdsworth)

Bromage was our previous Board director, and has been highly active in the Board and other SALT committees (e.g. FAC, BEC, SSWG). UCLan has made extensive contributions to the SALT Collateral Benefits Programme (SCBP), has hosted successful SALT Stobie scholarships, and has provided UCLan's distance learning university-level Astronomy courses (at discounted rates) for SALT engineers, operators and other staff for more than 10 years, as well as supporting visiting graduate students. Their SALT science interests involve collaborations within UKSC (with Keele and Armagh) and with SA, in particular with NWU and SAAO.

2. Open University (Andrew Norton, Carole Haswell, Stephen Serjeant, Marcus Lohr)

Science interests range from the "Dispersed Matter Planet Project" (Haswell), which has identified a key population of rocky exoplanets orbiting bright nearby stars and studied dust from catastrophically disintegrating planets (such as Kepler 1502b), to studies of variable star populations and unique individual variables from SuperWASP (Norton, Lohr). Serjeant and Marchetti (now at SAAO) coordinate the "SALT Gravitational Lensing Legacy Program" to pioneer a major new strong gravitational lens selection method, combining Herschel Space Observatory wide-area sub–mm observations with multi-wavelength ancillary data, generating the largest (> 500) sample to date of homogeneously selected lens candidates and obtaining SALT spectroscopy for most of them.

3. Armagh Observatory (Simon Jeffery, Gavin Ramsay, Jorick Vink, Gerry Doyle)

Armagh SALT science focuses on stellar remnants, massive stars, ultra-compact binary systems, and solar-system science, with extensive effort on stellar pulsations and abundance analyses using SALT's RSS and HRS. They have collaborations within UKSC and with SA (SAAO, UCT and UWC).

4. Keele University (Jacco van Loon)

Keele's main interests in SALT have been to exploit RSS' Fabry–Pérot mode to map emission as well as absorption features in nearby galaxies, and long-slit spectroscopy of various types of stars and of a peculiar AGN.

5. University of Nottingham (Peter Sarre)

Nottingham has had significant involvement in SALT administration (UKSC Board director for 4 years and Chair of the Finance & Audit Committee (FAC) for 3 years), as well as funding a post-doc (6 months) and two graduate students (2 months each) to work on technical and software development for SALT. Science interests are in molecular astrophysics and galaxies, making observations with RSS (long-slit and Fabry–Pérot) and HRS.

6. University of Southampton (Phil Charles, Malcolm Coe, Christian Knigge, Diego Altamirano, Tony Bird, Poshak Gandhi, Mark Sullivan)

As well as being the current UKSC Board director for SALT, Charles was SAAO Director for 7 years and, together with many of the Southampton Astronomy Group, is actively involved in the SA-led SALT Large Science Programme "Observing the Transient Universe", where they focus on black-hole, neutron star and white dwarf X-ray binaries, usually in association with other ground-based (e.g. ASASSN, OGLE, MASTER) and space-based (e.g. Swift, MAXI, ASTROSAT) facilities. The ASTROSAT observations include another major SALT partner, India. Sullivan is involved in SN–cosmology studies, which is part of the SALT long-term programme on supernovae. SALT is also used for rapid follow-up spectroscopy of outbursting X-ray sources in the SMC arising from the weekly Swift/S–CUBE monitoring (Coe).

SALT Board member: Phil Charles, University of Southampton

UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL (USA)

The University of North Carolina at Chapel Hill (UNC–CH) is the flagship research university and second largest of the campuses of the University of North Carolina System. Chartered in 1789, the university first enrolled students in 1795, making it one of three schools to claim title as the oldest public university in the United States. UNC–CH ranks 33rd in global universities, 23rd in all US universities, 5th in top public schools, and 9th in best value schools. It offers degrees through 14 colleges and the College of Arts and Sciences to almost 30,000 students from North Carolina (minimum 85%) and the other U.S. states, as well as from 47 other countries. UNC–CH also offers study abroad programs in 70 countries. All undergraduates receive a liberal arts education and as juniors have the option to pursue a major within the professional schools of the university or within the College of Arts and Sciences. The campus covers 3 km^2 of Chapel Hill's downtown, a town of about 80,000 people, and is one arm of North Carolina's tech-heavy Research Triangle, the other arms defined by Duke University in the city of Durham and North Carolina State University in capital city Raleigh. The Morehead Planetarium and Science Center on the UNC–CH campus features a digital projector and professional, fully robotic 0.6-m aperture research telescope with CCD cameras and spectrograph. The telescope is part of the global Skynet telescope network developed and run from UNC–CH. The analog version of the planetarium trained Mercury, Gemini, and Apollo astronauts in celestial navigation, a skill much appreciated by Commander James Lovell during the ill-fated flight of Apollo 13.

Astrophysics research at UNC–CH is conducted by two theoretical cosmologists, two experimental nuclear astrophysicists, five observational astronomers, a general relativist, and a gas dynamicist. These faculty are joined by a half dozen post-doctoral fellows and by approximately 25 graduate students. Many efforts focus on the SOAR 4.1-m telescope on Cerro Pachon in Chile that all use remotely from UNC–CH. Its Goodman spectrograph, from which the SALT RSS was derived, was built in the extensive and modern machine shop in the Physics and Astronomy Department.

Several faculty have worked with SALT products. Prof. Nicholas Law's group at UNC will shortly begin using SALT for exoplanet follow-up from their Evryscope and TESS surveys (TESS is NASA's next-generation, all-sky transit-detection satellite to launch soon). The Evryscope is a 700–megapixel array of telescopes on a common mount that together image 8,000–square-degrees of the Southern sky every two minutes from CTIO in Chile. Images can be co-added for many minutes before they reach deep enough to overlap stars. Evryscope is discovering planets in exotic systems, and is capable of confirming long-period large planets seen only once or twice in TESS's light curves. It is already enabling a significant fraction of the Large Synoptic Survey Telescope's time dependent science. SALT's High–Resolution Spectrograph (HRS) will enable false-positive rejection and eventually mass measurements for dozens of planet candidates from the Evryscope and TESS. SALT's Fabry–Pérot capability is of particular interest to UNC astronomers because its wider field and more extensive wavelength coverage complements the Fabry–Pérot system behind SOAR's laser adaptive optics system. SOAR will soon have a modern IR spectrometer in its rapidly selectable instrument complement, enabling prompt follow-up spectroscopy of time variable phenomena.

Prof. Chris Clemens is working with Lisa Crause from SAAO to develop a high throughput spectrograph for SALT using the patented curved volume-phase-holographic gratings that he developed with Darrah O'Donoghue (SAAO). That is a major commitment to SALT's future because it will allow very efficient follow-up of time-variable targets from Evryscope and LSST.

SALT time is open to everyone at UNC, with priority to student projects. SALT will also become more attractive to the local time-domain people with the new instruments to be added.

SALT Board member: Cecil Gerald

UNC's Evryscope located at Cerro Tololo in Chile.

The American Museum of Natural History's Rose Center for Earth and Space in New York City.

THE AMERICAN MUSEUM OF NATURAL HISTORY (USA)

The American Museum of Natural History is one of the worlds preeminent scientific and cultural institutions. Since its founding in 1869, the Museum has advanced its global mission to discover, interpret, and disseminate information about human cultures, the natural world, and the Universe through a wide-ranging program of scientific research, education, and exhibition. With 200 active researchers, including curator/professors, postdoctoral fellows, Ph.D. and Masters degree students, and research associates and assistants, AMNH is the only institution in North America that is both a research university and a museum, hosting over 5 million visitors each year.

Astronomy has been part of AMNH since the opening of the Hayden Planetarium, partly funded by philanthropist Charles Hayden, in 1934. The completely rebuilt Planetarium, opened in 1999, is a 30-m diameter sphere inside an 8 story-high glass cube, which houses the Star Theater. The theatre uses high-resolution fulldome video to project space shows based on scientific visualization of current astrophysical data. A customized Zeiss Star Projector system replicates an accurate night sky as seen from Earth. The AMNH Astrophysics research department is responsible for the content of spaceshows, for conducting research in astrophysics, and for training graduate students and postdoctoral fellows.

AMNH became a member of SALT in 2008 on the basis of a gift from the late Paul Newman. AMNH astrophysicist Michael Shara became Chairman of the SALT Board in 2012, and continues to serve in that position.

Prof. Shara uses SALT to study cataclysmic binary stars – novae, the stars that give rise to them, and the ways that they hide from astronomers during the millennia between eruptions. He and his Polish and South African colleagues have recently recovered the star that gave rise to the nova of 1437 A.D., chronicled by Korean Imperial astrologers. The old nova has transitioned to become a dwarf nova, as predicted decades ago. That binary star's characteristics were determined by Shara and colleagues using SALT, and the results were published in the journal Nature in 2017. Shara has also studied the descendants of the most massive binary stars, which give rise to the binary black holes recently discovered by LIGO. He and his South African colleagues have demonstrated that mass transfer in such binaries spins up the black hole progenitors – O stars in O+WR star binaries – to high speeds.

AMNH Postdoctoral Fellow (and now Assistant Professor at the College of Charleston) Ashley Pagnotta has been using SALT to measure the brightnesses of novae observed over the past century to test whether they continue to fade until they become dwarf novae or fainter systems. She and research Associate Dave Zurek have also searched for nova shells around asynchronous, strongly magnetic cataclysmic binaries. Their non-detection is puzzling, and an important clue in understanding these binary stars.

Postdoctoral Fellow Adric Riedel (now at the California Institute of Technology) used SALT's Robert Stobie Spectrograph to characterise 79 nearby M stars in 77 star systems. Radial velocities, Hα, lithium and potassium line indicators isolated 44 very young stars, including some not known to be members of any local moving groups.

SALT Board member: Michael Shara (chair)

SCIENCE HIGHLIGHTS

SCIENCE HIGHLIGHTS:

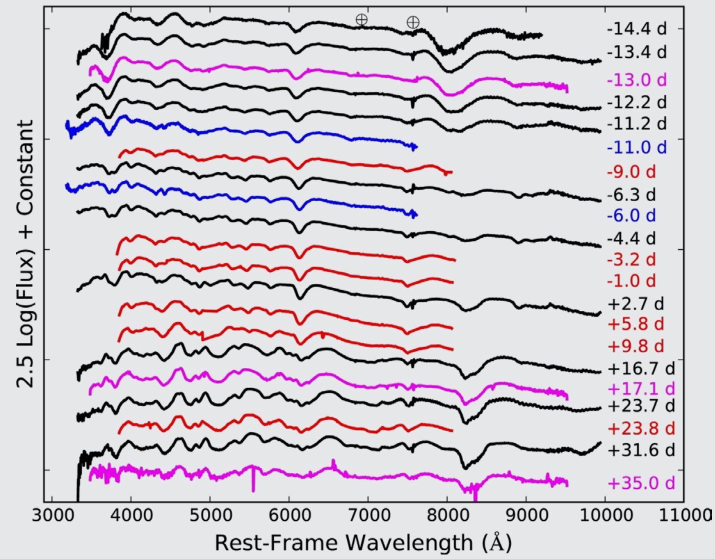
EXTRAGALACTIC ASTRONOMY 26

CAUGHT IN THE ACT: EARLY OBSERVATIONS OF THE NEARBY TYPE IA SUPERNOVA SN 2015F

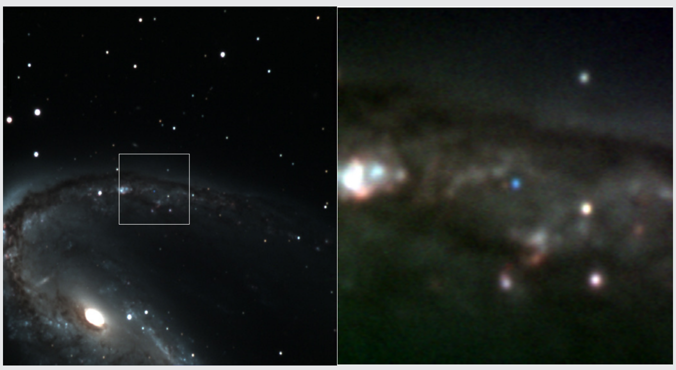
Understanding the physics of supernova (SN) Ia explosions, and the progenitors of SNe Ia, remains an important topic in astrophysics. Despite the increased quantity and quality of observations over the last decade, the detailed physics of such explosions is still uncertain. SN 2015F is an example of a rare, slightly sub-luminous SN Ia occupying the region between normal SNe Ia (used in cosmology) and events called 'SN1991bg-like', that is, events that are faint and evolve quickly. SN 2015F is rapidly becoming one of the best-studied SNe Ia: Regis Cartier, together with Mark Sullivan and Mat Smith from the University of Southampton and an international team conducted an intensive follow-up campaign using the RSS at SALT, which included early observations from as many as 9 days before the explosive event.

The RSS spectra show C II absorption, tracing unburned material from the progenitor CO white dwarf star. The team's spectral modelling shows strong evidence for iron peak elements (Fe II, Cr II, Ti II, and V II) expanding at velocities >14 000 km/s, suggesting mixing in the outermost layers of the SN ejecta. Intriguingly, an unusual absorption feature at 6800 Å was also detected. The authors argue that this is an Al II line, a line that was never seen before in SNe Ia. The nucleosynthesis of detectable amounts of Al II would argue against a low-metallicity white dwarf progenitor star.

In the meanwhile, the observing campaign presented here has been complemented with observations using other world-class facilities over the last 3 years: early HST spectra, late time nebular spectra using Gemini and VLT, and very late time photometry using HST and VLT. All these complementary observations will help to place constraints on the possible progenitors of SN 2015F.



Optical spectral sequence of SN 2015F.
The spectra range from -14 days to +35 days.
The different telescopes are colour coded:
black = NTT, red = SALT,
magenta = ANU 2.3-m, blue = FTS 2-m.
The positions of the main telluric features are marked at the top.



Left panel:
Composite colour image of SN 2015F at 350 d after the explosion.
The white rectangle corresponds to a 48" X 48" box centred on the SN.

Right panel:
48" X 48" box centred on SN 2015F (blue point source).

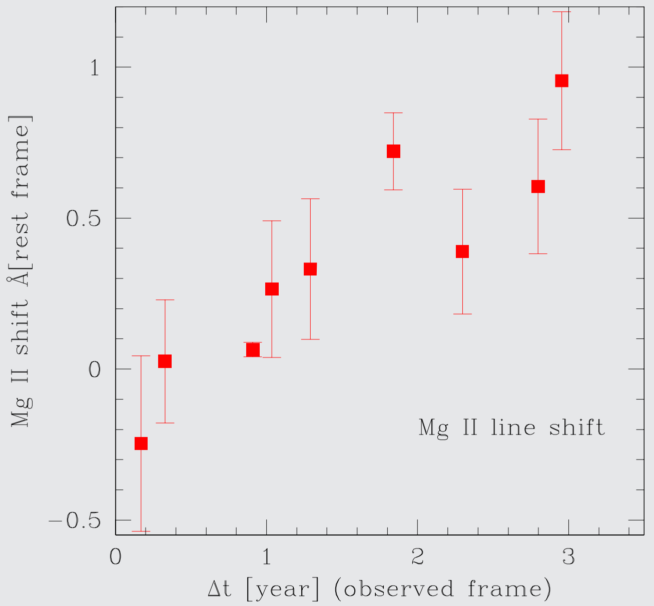
Cartier, R., et al., 2017/02, MNRAS 464, 4476: Early observations of the nearby Type Ia supernova SN 2015F

HE 0435–431: SALT QUESTIONS THE BINARY INTERPRETATION OF THE QUASAR LINE DRIFT

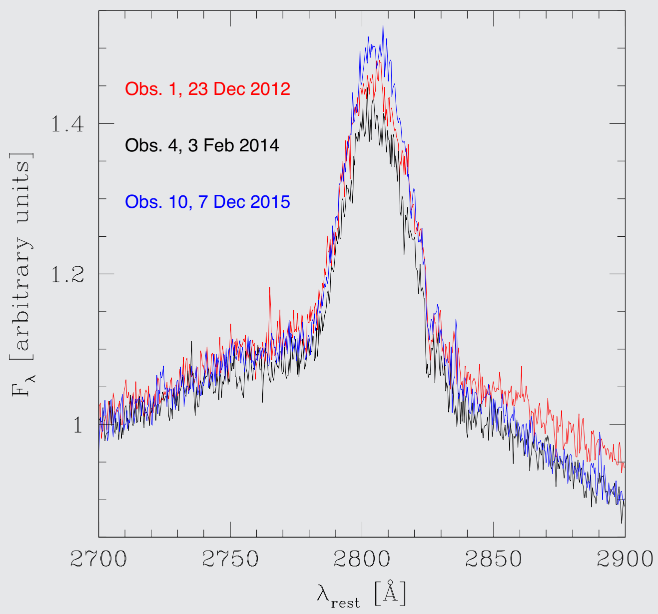
The drift of the broad emission lines in quasars is frequently considered a signature of the binary black hole in the system. The substructure and variability of the Mg II line can be used to identify which part of the line comes from a medium in Keplerian motion. Bozena Czerny from the Nicolaus Copernicus Astronomical Center (CAMK) in Warsaw therefore decided to initiate a long term SALT programme that monitors the Mg II emission line in several intermediate redshift quasars where the line is visible in the optical band. Justyna Średzińska, also from CAMK, is part of the team and analysed the spectra of the bright quasar HE 0435–431 at a redshift of z=1.2.

SALT's RSS spectra of HE 0435–431 show a very fast and systematic drift of the prominent Mg II line during the observing period of three years (2012 – 2015). Justyna and her colleagues further found that the measured acceleration is too large to be consistent with a binary black hole interpretation since it would locate the secondary black hole well within the Broad Line Region (BLR) while no perturbations of the underlying disk are observed. Also the broad band spectrum of the quasar looks typical for bright quasars, with a well developed Big Blue Bump. In comparison, the famous binary system OJ 287 is very different since the accretion rate onto the more massive black hole is small, an inner advection dominated accretion flow (ADAF) has most likely developed, and the secondary black hole passes through an optically thin and low density plasma. The density and the surface density of the disk in HE 0435–431 is orders of magnitude larger, so the effect of the passage should be more spectacular.

A more likely interpretation is the precession of the inner part of the disk which illuminates the outer disk and the BLR. Such a precession is seen in many radio-loud objects where it leads to a helical structure in the jet. There are not enough constraints on the precession mechanism yet since the trend so far is linear without a clear signature of a period. Czerny and her team have therefore decided to continue the SALT monitoring of this object.



Shift of the Mg II line in Observations 1 to 9 with respect to Observation 10, calculated directly from the data.



Three examples of quasar spectra in the Mg II region of HE 0435–431, renormalised to the 2700 Å flux, clearly show variations of the Mg II line, but accompanied with the variability of the underlying Fe II and the power law slope.

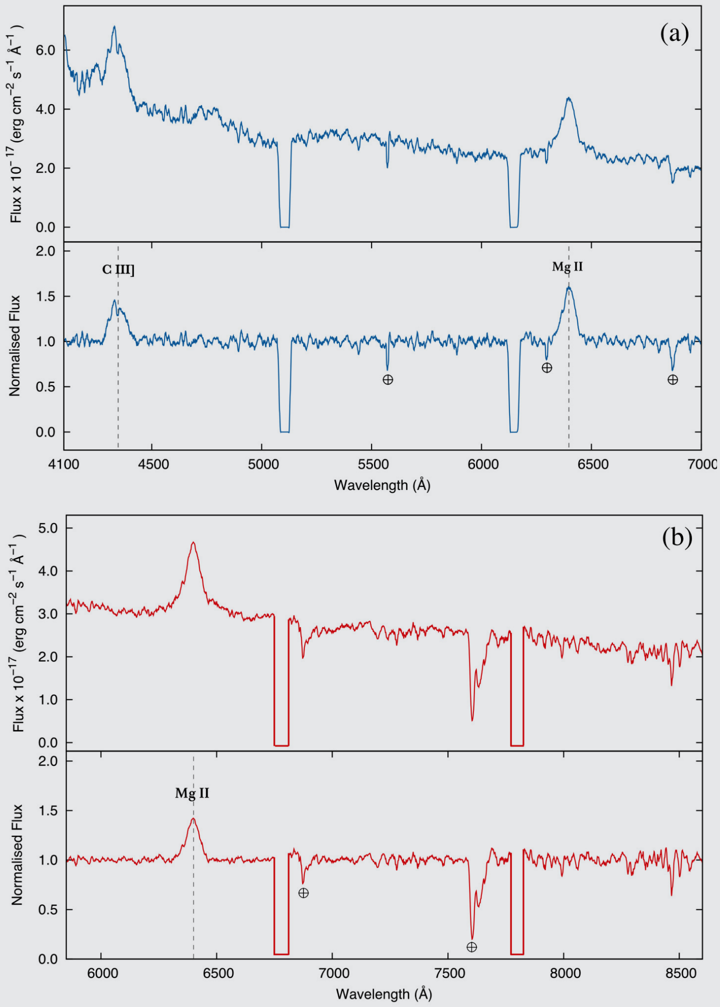
Średzińska, J., et al., 2017/05, A&A 601, 32: SALT long-slit spectroscopy of quasar HE 0435–4312: fast displacement of the Mg II emission line

SALT SPECTROSCOPIC CLASSIFICATION OF *FERMI*-LAT BLAZAR CANDIDATES OF UNKNOWN TYPE

Among the most violent astronomical objects in the Universe are a subclass of Active Galactic Nuclei (AGN) known as blazars. Multi-wavelength analyses play a crucial role in constructing a complete picture of these blazars, in particular of their accretion-black hole system with superluminal jets emerging from the nucleus. Being among the most energetic objects in the universe, blazars are bright at γ-rays, and AGNs observed with the *Fermi* γ-ray space telescope are thus dominated by blazar sources, though they are often not well classified.

Masters student Lizelke Klindt from the University of Free State and her collaborators decided to contribute to this task by increasing the number of classified, and well understood, *Fermi*-LAT sources, which will also add insights to the extragalactic γ-ray sky. They identified a target sample of nineteen blazar candidates of uncertain type (BCU) in the *Fermi*-3LAC catalogue with the aim (1) to classify the candidate blazars, (2) to determine distances to these objects via redshift measurements, (3) to construct Spectral Energy Distributions (SEDs) and (4) to search for Very High Energy (VHE) sources.

The unique optical spectra of blazars can be used as fingerprints to identify candidate sources and to distinguish between the two subclasses, BL Lacertae (BL Lacs) objects and Flat Spectrum Radio Quasars (FSRQs). Optical spectra of BL Lacs lack emission line features (or have only weak features) due to the dominant jet emission, with occasional absorption features from the host galaxy. FSRQs on the other hand exhibit strong and broad emission lines imprinted on a power-law continuum. Therefore, to fulfil the first two aims of the project, Lizelke decided to obtain spectroscopic observations of the first six *Fermi*-LAT BCU sources with SALT using the RSS spectrograph. Based on the identified spectral lines they have classified three of the sources as FSRQs and the remaining targets as BL Lac objects, determining concrete redshifts for four sources with a range of $0.106 < z < 1.930$. One of the sources also turned out to be a good candidate for VHE observations.



The average spectrum of the blazar 3FGL J0200.9–6635 obtained with the RSS/SALT.
The blue configuration spectrum shows broad emission line features from C III and Mg II lying at a redshift of z = 1.28 ± 0.01. The broad lines classify this source as an FSRQ.

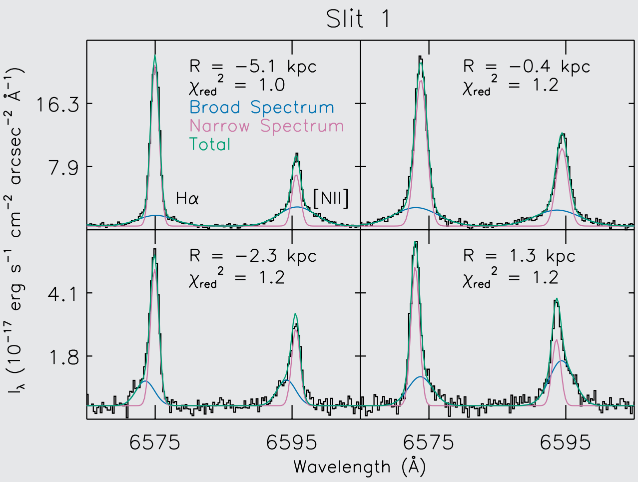
Klindt, L., et al., 2017/05, MNRAS 467, 2537: Optical spectroscopic classification of a selection of Southern hemisphere Fermi-LAT unclassified blazars.

SALT DETECTS EXTRAPLANAR DIFFUSE IONISED GAS IN THE SOUTHERN PINWHEEL GALAXY

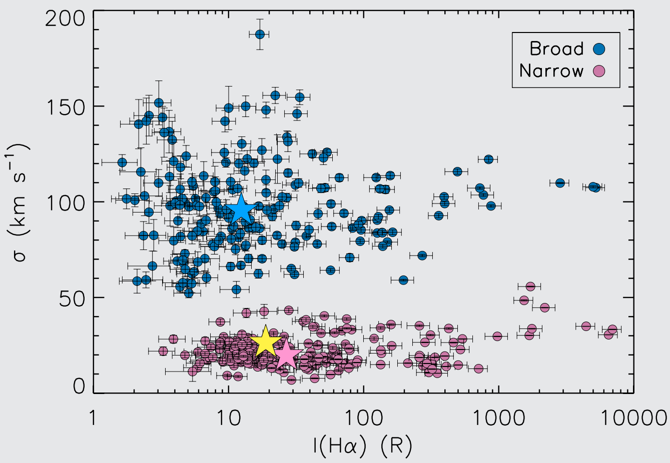
In galaxies with star formation rates per unit area at least as high as the Milky Way's, layers of warm, ionised gas are commonly observed with exponential electron scale heights of ~1 kpc that exceed their thermal scale heights by factors of a few. Scientists would like to understand the extent to which extraplanar diffuse ionised gas layers are evidence of the galactic fountain, wind and/or accretion flows that drive galaxy evolution.

Erin Boettcher and her colleagues from the University of Wisconsin–Madison are among the first to study this extraplanar diffuse ionised gas in a face-on disk galaxy by using SALT's great ability to detect diffuse emission. First, they developed a Markov Chain Monte Carlo method to isolate and characterise extraplanar diffuse ionised gas emission using optical emission-line spectroscopy of nearby, face-on disk galaxies. The technique separates planar emission, that is, H II regions, and extraplanar emission by decomposing the Hα, N II, and S II emission lines into multiple Gaussian components and identifying extraplanar diffuse ionised gas emission based on its characteristic emission-line ratios and rotational velocity lag with respect to the disk, as shown in in figure to the left.

The authors obtained RSS longslit spectroscopy of the nearby, face-on galaxy M83 (also called the Southern Pinwheel Galaxy) to perform a first full characterisation of the emission-line properties, vertical velocities, and vertical velocity dispersions of an extraplanar diffuse ionised gas layer. The analysis of the data revealed a vertical velocity dispersion that exceeds the horizontal velocity dispersions observed in edge-on disk galaxies by factors of a few (see right-hand figure). This suggests that the extraplanar diffuse ionised gas layer in M83 is supported in a quasi-equilibrium state by anisotropic, random motions punctuated by local bulk flows near star-forming regions. The authors are currently analysing observations of low-inclination galaxies with a range of star formation rates to assess the dependence of these results on underlying disk properties.



Gaussian decomposition of the spectra into a narrow (pink) and broad (blue) component where narrow and broad refer to the planar and extraplanar emission, respectively.



Line widths of the broad component (blue) greatly exceed those of the narrow component (pink), suggesting that the former originate from a thicker gaseous disk. The median values for the broad (σ = 96 km/s), narrow (σ = 20 km/s), and single (σ = 26 km/s) components are shown with the blue, pink, and yellow stars, respectively.

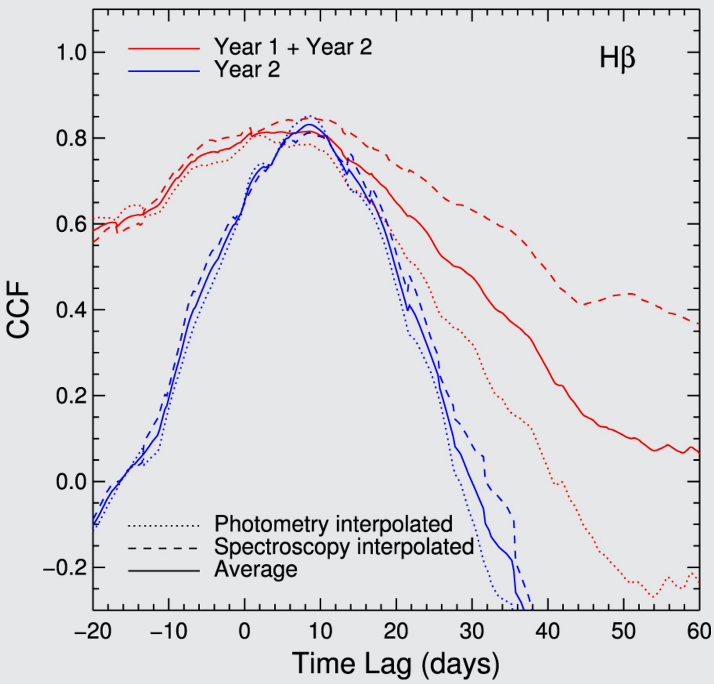
Boettcher, E., Gallagher, J. S., III, & Zweibel, E. G., 2017/08, ApJ 845, 155: Detection of extraplanar diffuse ionized gas in M83

REVERBERATION MAPPING OF PG 0934+013

Active galactic nuclei (AGNs) are the bright core regions of galaxies that have a supermassive black hole (SMBH) in their centre that is accreting material from their surroundings. The accretion process produces continuum emission, which in turn induces emission lines from a region of fast-moving gas clouds near the black hole (Broad Line Region, BLR) and from more distant, lower density gas clouds (Narrow Line Region, NLR). If it is assumed that the kinematics of the BLR gas are governed by the gravitational potential of the central black hole, the mass of the supermassive black hole in their core can be determined using a technique called reverberation mapping. This technique uses the measured time delays between the continuum variability and the "echoes" it produces in the BLR to measure the light-travel distance between the BLR and the SMBH, which is then directly related to the mass of the SMBH.

Songyoun Park from Seoul National University in Korea together with Encarni Romero–Colmenero and Steve Crawford from SALT and an international team present the variability and time-lag measurements of PG 0934+013 based on a spectroscopic and photometric monitoring campaign over a two year period.

The observations comprise 46 epochs of spectroscopic data using SALT/RSS with ~1 week cadence over two sets of four month-long observing period, and, during the same periods, 80 epochs of B–band imaging data using a few 1-m class telescopes. Due to the seven month gap between the two observing periods they separately measured the time lags of broad emission lines for each year, comparing the emission line light curve with the B–band continuum light curve using cross-correlation function techniques. While the time lag from Year 1 data was not reliably determined because the Hβ flux was monotonically decreasing during this period, they find for Year 2 a time lag for the Hβ line to be 8.5 days ± 2.1 days in the observed frame. Using the rms spectrum of the same period, the team measured the Hβ line dispersion to be 668 ± 44 km/s (after correcting for the spectral resolution). Adopting an earlier determined virial factor f = 4.47 they find the black hole mass to be $(3.1 \pm 0.9) \times 10^6$ Solar masses based on the Hβ time lag and velocity.

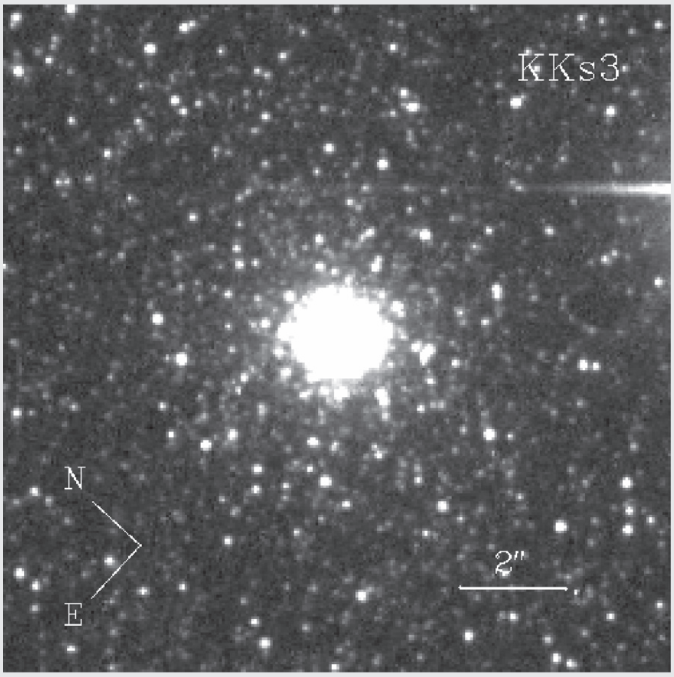


Cross-correlation function between the B–band continuum and Hβ emission line, for Year 1 + Year 2 (red) and Year 2 (blue). Cross-correlation function values are calculated by interpolating photometry data (dotted) or spectroscopy data (dashed) data. Solid lines denote averages.

Park, S., et al., 2017/10, ApJ 847, 125: Reverberation Mapping of PG 0934+013 with the Southern African Large Telescope

HOW DO NUCLEI OF DWARF SPHEROIDAL GALAXIES COMPARE WITH MASSIVE GLOBULAR CLUSTERS IN OUR GALAXY?

Modern star-formation theory implies that a huge system like the Milky Way was possibly built from small blocks like dwarf galaxies, and in particular from dwarf spheroidal galaxies (dSphs). It is obvious that such small blocks were totally destroyed while merging with our Galaxy, but at the same time compact objects such as the nuclei of dSph must have survived and are possibly still visible as today's globular clusters (GCs). Russian scientists Margarita Sharina and Vladislav Shimansky together with SALT astronomer Alexei Kniazev decided to investigate the connection between dSphs and GCs by studying the star-formation history of two nearby dSphs, KKs 3 and ESO 269–66. Since their nuclei are very old and very massive, they are comparable to the very high end of the GC mass distribution.



HST image of the central globular cluster in KKs 3.

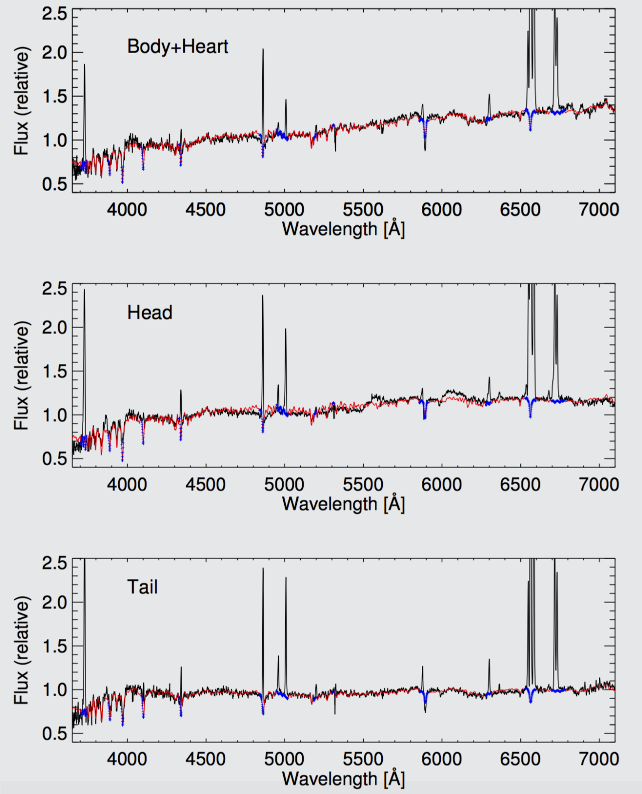
These two dSphs have similar star formation histories with three star forming bursts, where the oldest ones in each, 12–14 Gyr ago, were the most powerful. However, the environments of the two galaxies are very different. KKs 3 is one of the few truly isolated dSphs within 10 Mpc and one of the faintest known field galaxies. ESO 269–66 is a satellite of the giant lenticular galaxy NGC 5128 and is unusual in the sense that the stellar metallicity dispersion in it is surprisingly large for a faint dSph.

The authors used SALT's RSS to obtain medium-resolution spectra of the nuclear GCs in the two galaxies. Ages and chemical compositions were analysed using their method of computing integrated-light synthetic spectra of GCs using models of stellar atmospheres according to a selected mass function and stellar parameters defined by a particular stellar evolutionary isochrone. They determined the age of both dSph nuclei to be 12.6 ± 1 Gyr and to have a metallicity of [Fe/H] = -1.5 ± 0.2 dex. Furthermore, they find that the spectra, ages, chemical compositions and structure are similar to several massive Galactic GCs which have a slightly higher metallicity of [Fe/H] ~ -1.6 dex. All the Galactic GCs possess an Extended Blue Horizontal Branch and multiple stellar populations. Five of the selected Galactic objects are iron-complex GCs. The authors conclude that all the observed GCs, which are found now in very different environments, had similar conditions of their formation about 1 Gyr after the Big Bang.

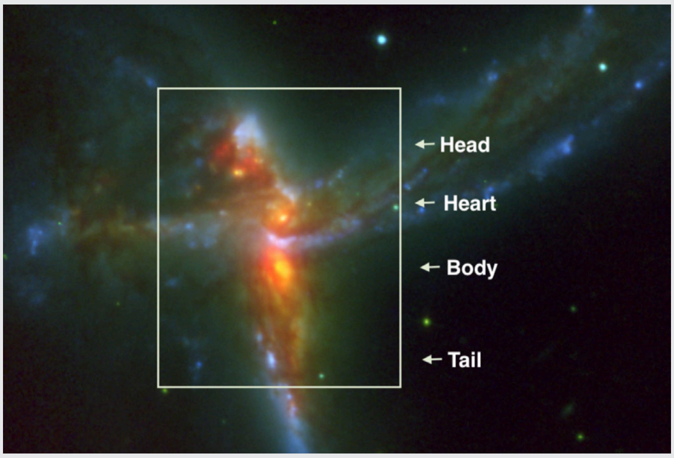
Sharina, M.E, Shimansky, V.V. and Kniazev, A.Y., 2017/10, MNRAS 471, 1955: Nuclei of dwarf spheroidal galaxies KKs 3 and ESO 269–66 and their counterparts in our Galaxy

TIME-STAMPING STAR-FORMATION IN A MULTIPLE GALAXY MERGER

An RSS study of the luminous infrared galaxy (LIRG) IRAS19115–2114, at 200 Mpc distance, was one of the first SALT data papers, published in 2008 by Petri Väisänen from SALT/SAAO and his collaborators. Based on VLT adaptive optics imaging and RSS spectroscopy the authors found that the system was actually a triple merger. They named it the Bird due to its appearance. The star-formation characteristics were unusual and the violent ULIRG-level starburst was apparently not in the nucleus. The group thus re-visited the galaxy using VLT/SINFONI integral field observations and RSS long-slit spectroscopy. The new study by the same lead author confirms that an off-nuclear minor companion, a pure starburst, dominates the current star formation of the Bird with 60–70% of the total. The NIR Integral Field Units (IFU) data cube revealed the kinematics even in the most obscured parts of the complex system, where the NIR line ratios showed ionisation characteristics and constrained the youngest starburst ages.



RSS spectra (black) of various Bird components with stellar population fits (red). These fits and line-ratios from SINFONI IFU observations were used to age-date the Bird components and find gas flows.



Three-colour (BIK , HST+VLT) image of the Bird LIRG, a complex star-starburst merger where the current star-formation is dominated by the "Head" component, while the "Body" is already quenched with no significant current star-formation, but rather strong outflows of gas.

Full-spectral fits to the RSS data were used to determine stellar population metallicities and ages, as well as star formation histories, and both data-sets were used together to find gas flows of neutral gas, ionised gas, and molecular gas.

The youngest starburst was determined to have a 4–7 Myr age. The most massive nucleus, in contrast, is quenched. with a starburst age of > 40 Myr, and it shows hints of budding AGN activity. The secondary massive nucleus is at an intermediate stage. The two major components have signs of an older stellar population, consistent with a starburst triggered 1 Gyr ago in a first encounter. The simplest explanation of the history is that of a multiple merger, where the strongly star-forming component has joined latest. Very interestingly, the authors detect multiple gas flows in different phases over the different components. The strongest starburst shows the least flows, mainly in ionised gas, while the quenched, most massive nucleus appears to be the source of the strongest gas flows, seen in multiple components of ionised and molecular gas. It also shows a strong outflow of neutral cool gas (detected in NaD absorption) that has had time to spread over the whole system, likely linking the source of it to an earlier starburst activity before quenching. In the future, these timescales correlating star-formation triggering and quenching with unique gas flows should be used to constrain galaxy evolution models.

Väisänen, P, et al., 2017/10, MNRAS 471, 2059: Shutting down or powering up a (U)LIRG? Merger components in distinctly different evolutionary states in IRAS 19115–2124 (the Bird)

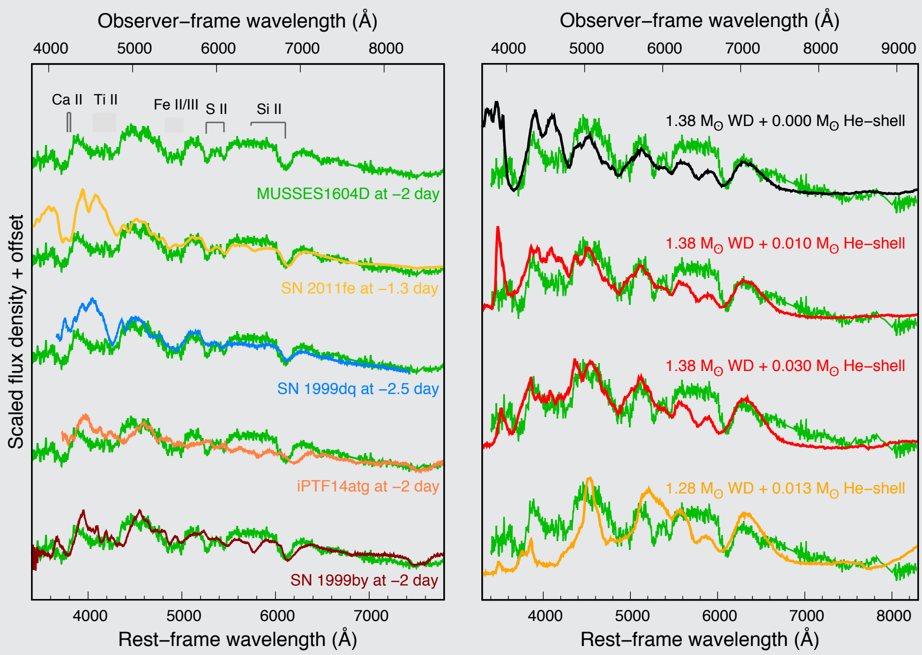
A SUPERNOVA THAT EXPLODES FROM THE OUTSIDE IN

Type Ia supernovae (SN Ia) are thought to be the thermonuclear explosions of white dwarfs that accrete material from a binary companion star. Though the exact nature of the progenitor system and the physics of the subsequent explosion are not completely understood, SN Ia are nonetheless used as cosmological distance indicators and led to the discovery that the expansion of the Universe is accelerating, driven by dark energy.

Recently, an international team led by Ji-an Jiang, a graduate student at the University of Tokyo, set up a program called MUSSES to find Type Ia SNe soon after explosion by using the Hyper Suprime–Cam mounted on the 8.2-m Subaru telescope. Such early-time observations can provide clues as to how SN Ia explode. In April of 2016, the team found an SN, called MUSSES1604D, within about 12 hours of its explosion. The early light curve showed some peculiar behaviour, making this object a prime target for spectroscopic follow-up with the RSS at SALT. The observations, led by Saurabh Jha of Rutgers University, showed that MUSSES1604D is a Type Ia SN at a redshift of z = 0.12 (corresponding to a distance of 1.5 billion light years), but with some odd spectral features, more like a hybrid of SN Ia subtypes (see figure).

In order to figure out the origin of this mysterious object, intensive computational simulations have been carried out based on different theoretical models. Jiang and his collaborators finally confirmed that the peculiar features of this SN are not consistent with predictions from standard scenarios, but instead can be naturally explained by an explosion mechanism that operates from the outside, inwards. In this scenario, the accumulation of helium on the surface of the white dwarf explodes first and drives an inward moving shock wave that then causes the carbon and oxygen core of the white dwarf to explode. This finding is the first evidence that robustly supports a theoretically predicted stellar explosion mechanism proposed in the early 1980s.

The left panel compares the spectrum of MUSSES1604D taken two days before the B-band maximum by SALT/RSS (green colour) to spectra of SNe Ia in different subtypes at the similar epoch. Simulated spectra at the same epoch from different models are shown in the right panel.



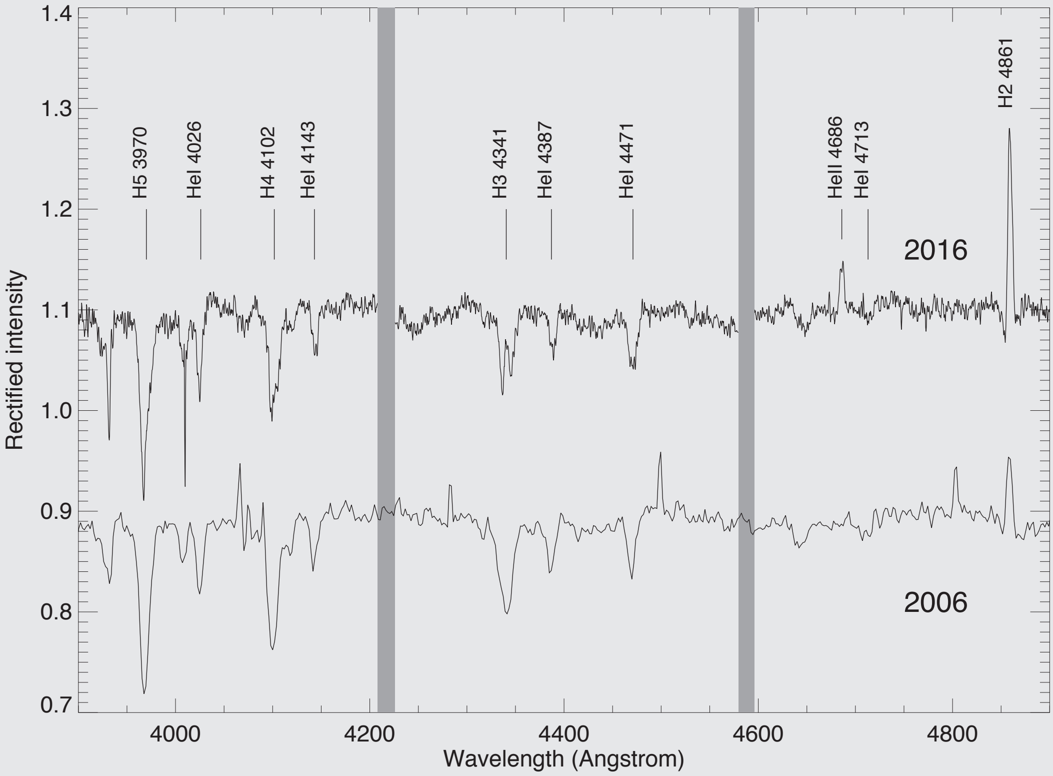
Jiang, J.-A., et al., 2017/10, Nature 550, 80: A hybrid Type Ia supernova with an early flash triggered by helium-shell detonation

THE 2016 SUPER-EDDINGTON OUTBURST OF THE BE/X-RAY BINARY SMC X–3

Observations of the Be/X-ray binary pulsar SMC X–3, under a SALT key programme on optical transients led by SAAO astronomer David Buckley, were used to help Lee Townsend from the University of Cape Town and his collaborators to understand the optical behaviour of the system during a recent super-Eddington outburst. This outburst was one of the brightest and longest outbursts ever observed from a Be/X-ray binary. It was extensively monitored by the Swift satellite to observe the X-ray behaviour and measure the system parameters for the first time. A SALT/RSS blue spectrum was taken and compared to an archival ESO 3.6-m spectrum taken during X-ray quiescence. This comparison showed an enhancement of the Hβ emission and an infilling of the Hγ absorption line during the outburst. This was interpreted as evidence that the circumstellar disc around the Be star had grown, causing the onset of the giant X-ray outburst from increased accretion of disc material onto the neutron star.

The RSS spectrum also showed He II in emission, which was not present in the archival spectrum. This provided good evidence that an accretion disc had formed around the neutron star.

Several RSS red spectra were also obtained and used alongside SAAO 1.9-m and archival spectra to observe the changes in the Hα line emission during the outburst. The SALT spectra helped the authors to confirm not only that the disc was bigger than during archival observations, but also showed evidence of rapid variability of this line emission on sub-day timescales. This is an unusual observation in Be/X-ray binary systems, which they interpreted as evidence of a time-variable or "clumpy" disc. This scenario also explains why the X-ray spin period observed by Swift was highly variable beyond the level expected from spin-up caused by a constant accretion rate.

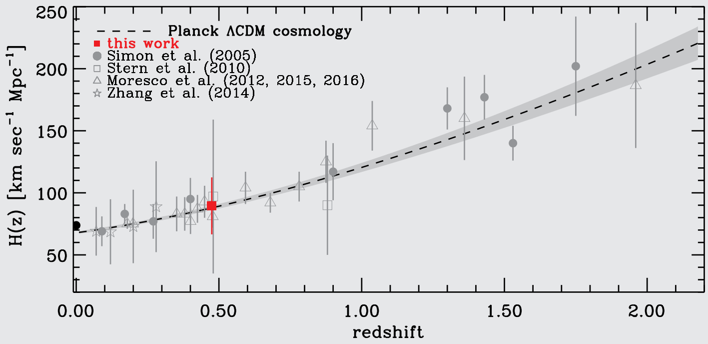


ESO 3.6-m spectrum from 2006 and SALT RSS spectrum taken during the 2016 X-ray outburst. The spectra are rectified and offset from 1.0 by 0.1 on either side for clarity. The vertical grey lines represent the RSS chip gaps.

Townsend, L.J., et al., 2017/11, MNRAS 471, 3878: The 2016 super-Eddington outburst of SMC X–3: X-ray and optical properties and system parameters

THE HUBBLE CONSTANT AT A REDSHIFT OF 0.5: AGE-DATING LUMINOUS RED GALAXIES

There have been a number of attempts to measure the expansion rate of the Universe using age-dating of Luminous Red Galaxies (LRGs). Assuming that stars in LRGs form at the same time, age-dating of two populations of LRGs at different redshifts can provide an estimate of the time difference associated with the corresponding redshift interval. This gives a direct estimate of the Hubble parameter or the cosmic expansion, H(z), at the average redshift of the two populations. This technique is also known as cosmic chronometers. Ph.D. student Ando Ratsimbazafy from the North-West University led a SALT/RSS pilot study to obtain long-slit spectra of LRGs at two narrow redshift ranges z~0.40 and ~0.55. She and her colleagues measured a value of the cosmic expansion of H(z) = 89 ± 23 (stat) ± 44 (syst) km/s/Mpc at a mean redshift of z=0.47. Ages were estimated by fitting single stellar population models to the observed spectra. This measurement represents one of the best estimates of H(z) at z ~0.5 via this method to date.

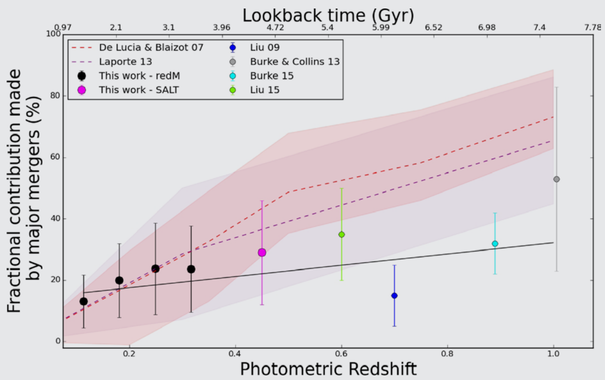


The estimated value of H(z~0.4) = 89 ± 23 km/s/Mpc from this work is represented by the red filled rectangle. Also shown are all available H(z) in the literature up to z ~ 2. The dashed line and the shaded regions are the non-fitted theoretical H(z) of a flat LambdaCDM model with its 1σ uncertainty obtained by the Planck Collaboration (with Ω_m = 0.308 ± 0.012, and H_0 = 67.8 ± 0.9 km/s/Mpc). The black point at z=0 is the HST measurement of H_0 = 73.8 ± 2.4 km/s/Mpc.

Ratsimbazafy, A.L., et al., 2017/05, MNRAS 467, 3239: Age-dating luminous red galaxies observed with the Southern African Large Telescope

MAJOR MERGERS DOMINATE THE STELLAR MASS GROWTH OF RECENT BRIGHTEST CLUSTER GALAXIES

How important are major mergers in the stellar mass build-up of brightest cluster galaxies (BCGs) at z < 0.5? Ph.D. student Danièl Groenewald from SAAO asked herself that question, and, together with SALT Astronomer Ros Skelton and other South African collaborators, used the RSS on SALT to measure the pair fraction of these BCGs, which is indicative of the merger rate. She determined that, on average, 24% of the stellar mass of present-day BCGs were accreted since z~0.32 and that major mergers can also account for the stellar mass growth seen in the intracluster light.



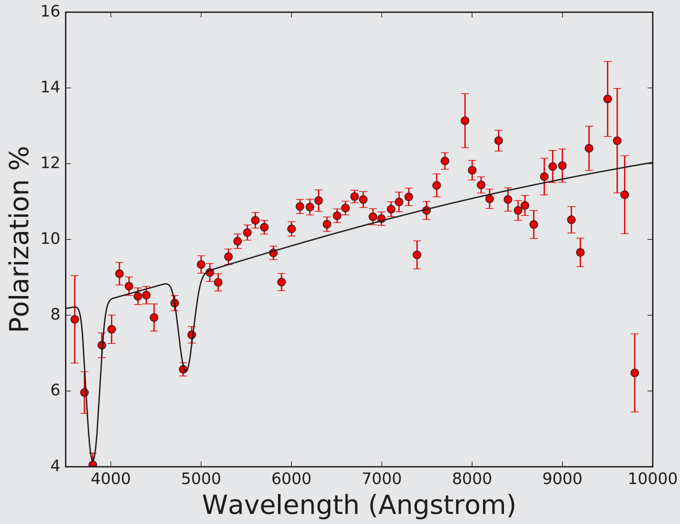
Comparison of the measured fractional contribution made by major mergers to the stellar mass of a present-day BCGs since a given redshift. The fractional contributions have been measured from the redshift they are plotted at, down to z = 0 (assuming f(mass) = 0.5). Dots are observations, shaded regions indicate model predictions. The solid and dashed lines, respectively, show the best linear fit to the observational studies and models.

Groenewald, D.N., et al., 2017/06, MNRAS 467,4101: The close pair fraction of BCGs since z = 0.5: major mergers dominate recent BCG stellar mass growth

SCIENCE HIGHLIGHTS: EXTRAGALACTIC

SALT SPECTROPOLARIMETRY DATA OF THE BLAZAR 4C+01.02

M.Sc. student Hester Schutte (NWU) is involved in the interpretation of spectropolarimetry data from SALT of a flaring active galactic nucleus, that is, a blazar called 4C+01.02. The optical emission of such systems is a combination of non-thermal synchrotron emission from a relativistic jet and thermal components originating from the host galaxy and the accretion disk. Spectropolarimetry may help to disentangle these different components. For this purpose, Hester has developed a code to model simultaneously the spectral energy distribution and wavelength-dependent optical polarisation resulting from such a superposition of different radiation components. The figure illustrates her fit to the spectropolarimetric data of 4C+01.02 taken in July 2016, which helped to disentangle the polarised jet-synchrotron emission from the unpolarised accretion-disk emission. It constrained the mass of the central black hole in this galaxy to ~ 2 x 10^9 Solar masses. The observations were taken as part of a Large Science Programme led by David Buckley (SAAO) of target-of-opportunity follow-up observations of astrophysical transients.



The model developed by Hester Schutte is fitted to the SALT spectropolarimetric data of 4C+01.02.

Böttcher, M., et al., 2017/09, Galaxies, 5, 52: SALT Spectropolarimetry and self-consistent SED and polarization modeling of blazars

Böttcher, M., et al., 2017, in proceedings of "7th Fermi Symposium 2017", Garmisch–Partenkirchen, Germany, 15–20 October 2017: SALT Spectropolarimetry and self-consistent SED and polarization modeling of blazars

SCIENCE HIGHLIGHTS:

STELLAR AND GALACTIC ASTRONOMY

38

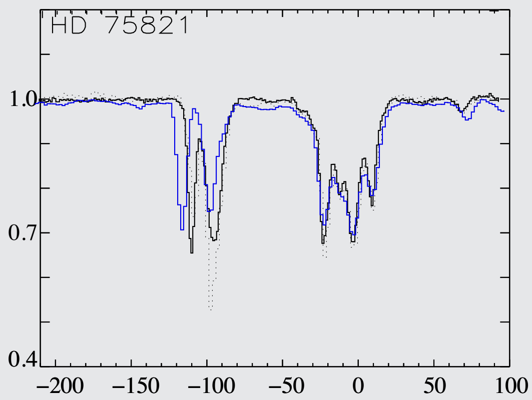
UNVEILING VELA: A STUDY OF THE VELA SUPERNOVA REMNANT THROUGH VARIABILITY OF INTERSTELLAR LINES

The interaction of supernova remnants (SNRs) with the surrounding interstellar medium (ISM) plays an important role in the study of many areas in astronomy ranging from the dynamics of the ISM to chemical evolution of the Galaxy to star formation. At a distance of 290 pc, the Vela SNR is the closest SNR to us and represents a special opportunity to observe the SNR–ISM interaction. The supernova explosion occurred about 11,000 years ago. The large size of the SNR, about 9 degrees in diameter, and the presence of many early type stars in the region of the sky has allowed the remnant gas to be studied through absorption lines along sight-lines across most of the remnant. A study from 1993 to 1996 showed several high velocity components (> 100 km/s), manifesting shocked SNR–ISM gas, to exhibit variability in their strength. However, the high velocity components are only present in stars that are at distances greater than 500 pc, 200 pc behind the SNR. The main interaction of the SNR, though, is expected with ISM clouds at a distance of 300 ± 50 pc that show moderate radial velocity components. No comparable large changes were seen in the low-velocity components of the lines which are plausibly attributable to the normal diffuse ISM. Time variability in ISM is a rare phenomenon so that changes in Vela are surely related to SNR–ISM interaction. Continued monitoring of interstellar absorption is required to follow these effects.

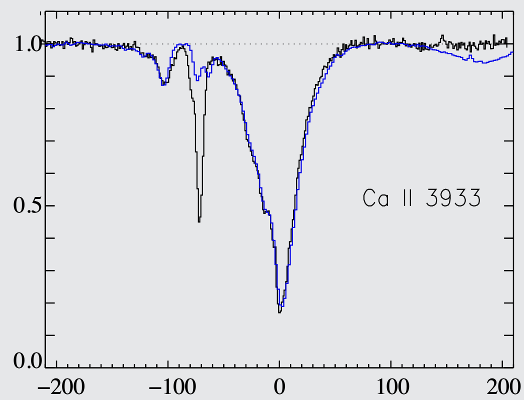
In pursuit of this goal, Neelamraju Kameswara Rao from India and his team surveyed Na I D profiles of 64 stars using the 2.3-m Vainu Bappu Telescope (VBT). A comparison with the published profiles revealed several interesting changes at both low and high velocities. Particularly striking was the disappearance of strong absorption components at low radial velocities seen towards three stars over the interval of 15 years. This time scale for the dissolution of cold clouds by the SNR shock is remarkably short and needs to be understood. Over the same time period, another star showed a strengthening of a low-velocity Na I D component though simultaneous Ca II K profiles were lacking. The latter are very important in understanding the physical nature of the time variability of these clouds, particularly regarding the degree of ionisation.

In 2015, the team used SALT HRS to observe the same three stars which now showed a dramatic disappearance of moderate velocity Na I D components. Mysteriously there were no changes in Ca II K profiles during this 15-year period. A possible explanation is that the Hydrogen Ly-α line produced by supernova shocks could have ionised the Na I without disturbing Ca II in the moderate velocity ISM clouds.

During the team's most recent run with SALT they acquired data for about 9 stars. Some of them demonstrate several significant changes in Ca II K profiles between 2017 and the 1993–94 period. Analysis of the spectra is in progress. SALT HRS spectra will also offer the opportunity to detect other ISM lines such as Ca I 4227Å, CH 4300Å and CH^+ 4232Å which are being studied presently.



Profile of Ca II K in the line-of-sight towards HD 75821 obtained with SALT on 2017 April 16 (blue line) is superposed on the 1993 (dotted) and 1996 (black line) profiles. The high velocity components, both negative and positive, seem to have been accelerated.



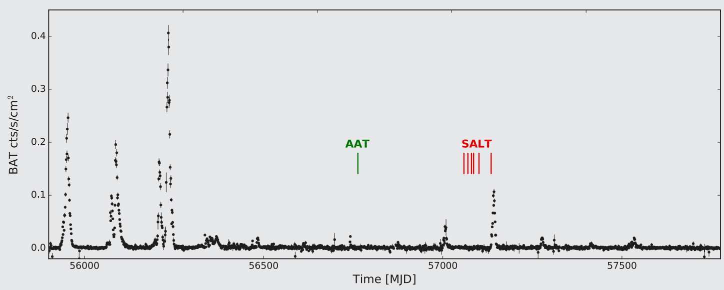
Profile of Ca II K in the line-of-sight towards HD 75129 obtained with SALT (blue line) on 2017 May 29 is superposed on a published 1996 profile (black line). The component at –67 km/s has weakened considerably by 2017

Kameswara Rao, N., et al. 2017/05, MNRAS 467, 1186: Unveiling Vela: time variability of interstellar lines in the direction of the Vela supernova remnant – II. Na D and Ca II

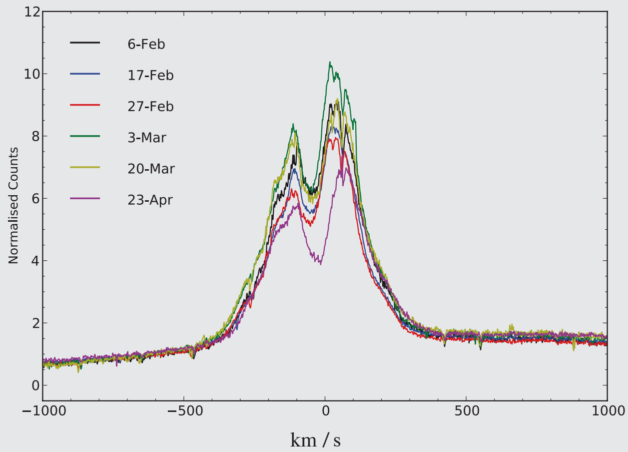
OPTICAL SPECTROSCOPY OF THE BE/X-RAY BINARY GX 304–1 DURING FAINT X-RAY PERIODIC ACTIVITY

GX 304–1, also called V850 Cen, is a Be/X-ray binary system (BeXRB) composed of an optical companion (V850 Cen, R mag ~12.6) and a pulsating neutron star. V850 Cen is a so-called Be star, that is, a B star with a circumstellar disk formed from expelled material whose spectrum is characterised by emission lines, especially of the Balmer series. BeXRBs are characterised by luminous X-ray outbursts powered by the accretion of matter onto the neutron star where the accreted matter is supplied by the circumstellar disk. Therefore, the X-ray activity and the Be-disk status are tightly entwined and need to be studied altogether. For this purpose, Christian Malacaria from the University of Tübingen in Germany and his collaborators performed optical monitoring of the source and compared its X-ray activity with the Be disk properties. They obtained SALT/HRS as well as AAT/UCLES spectra over the period of one year (2014/2015) and distributed along the orbital period of the binary system (~132 days). During this time, the X-ray source has shown only sporadic weak outbursts at periastron passages (see figure to the left). The authors have focused on the Balmer emission lines, and the characterisation of the circumstellar disk as compared to the geometrical and physical properties of the binary system. The main results are:

- The circumstellar disk was always present, although not always large enough to trigger X-ray outbursts, as derived from the presence of the Hα line which was always double-peaked but showed strong variations on a time scale of ~1 year (see right-hand figure).
- The observations indicate that the system is highly inclined at ≥ 60deg and may even be an edge-on system.
- The size of the circumstellar disk as seen in Hα increased from ~5.9 R_* in 2014 to ~11 R_* a year later. In comparison, the size of the Roche lobe at periastron is ~9 R_*, and thus the X-ray intermittent activity of GX 304–1 is a direct consequence of the circumstellar disk evolution.
- The theory for this source's binary configuration predicts inefficient truncation of the circumstellar disk by the orbiting neutron star, which seems to be consistent with the observations.
- The authors also detected the Hβ emission line in one of the spectra, where the Hβ emitting region is about half of the size of the Hα-emitting disk. The comparison of the equivalent widths of the Hα and Hβ lines confirm the luminosity class to be III-V.



Swift/BAT [15–50 keV] light curve of the long term GX 304–1 X-ray activity. Superimposed are the AAT/UCLES (2014 – green bar) and SALT/HRS (2015 – red bars) observations.



Evolution of the Hα emission line profile, as observed by SALT/HRS during one entire orbital period at the beginning of 2015. Horizontal axis units are km/s.

Malacaria, C., et al, 2017/07, A&A 603, 24: Optical spectroscopy of the Be/X-ray binary V850 Centauri/GX 304–1 during faint X-ray periodical activity

BW CIR: EVIDENCE FOR OPTICAL CYCLO-SYNCHROTRON EMISSION FROM THE HOT ACCRETION FLOW

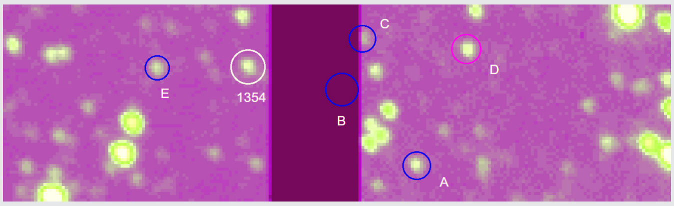
In a binary orbit with a companion star, black holes accrete matter in the form of a disk, where the inner part of the disk emits mostly in X-rays. Such X-rays from the geometrically thin, hot inner disk, however, can be reprocessed from the geometrically thick, cold outer part of the accretion disk and generate optical emissions. As a result, the optical emission appears delayed to the X-ray emission, and the timescale is of the order of light travel time from the inner to the outer part of the disk and therefore scales with the size of the accretion disk/reprocessing area. Recently it has been noticed that the optical variability faster than a few tens of seconds shows delayed anti-correlation with X-rays. This implies that the reprocessing scenario is not sufficient to explain the observed phenomena.

To test the reprocessing model further, Mayukh Pahari and his colleagues from India, South Africa and the UK took simultaneous optical and X-ray observations of the black hole X-ray transient GS 1354–64, also known as BW Cir, during the rising phase of the X-ray outburst. They used SALT's BVIT to obtain a high-resolution lightcurve which shows long-term variability of the order of a few hundreds of seconds accompanied by short flares of the order of a few seconds to a few tens of seconds. The authors confirm that a strong anti-correlation exists between both types of variability with optical photons leading X-ray photons. They also found a potential quasi periodic oscillations at ~0.018 Hz in both X-ray and optical power spectra.

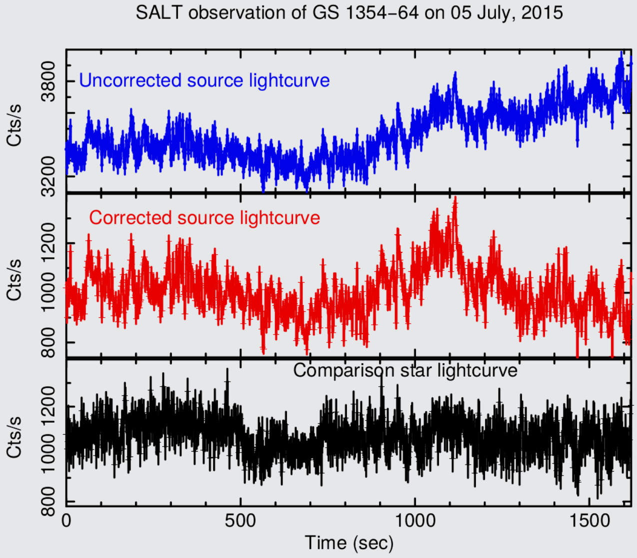
An alternative model for the origin of optical emission is the cyclo-synchrotron emission from the magnetised hot inner accretion flow. The existence of such a flow, particularly during the canonical hard state accretion, is evident from the hard state spectral analysis from all known black hole X-ray binaries. To investigate the origin of the optical emission in GS 1354–64, the authors estimate the luminosity of the self-absorbed cyclotron emission to appear in the optical band and compared it to the X-ray luminosity. They found that the optical luminosity is consistent with the cyclo-synchrotron origin of optical photons.

Moreover, the authors probed the hot inner flow with simultaneous broadband X-ray spectral modelling (using data from the Swift/XRT and INTEGRAL satellites) and find the presence of a cold, truncated disc (~0.12 keV) with the hot inner flow having the power-law photon index of ~1.48 and electron temperature ~90 keV. Pahari and his team conclude that an optically thin hot electron corona can co-exist with the geometrically thin disc, where the matter from the disc may evaporate to feed the corona. Therefore depending on the mass flow rate, the accretion flow consists of a cool accretion disc which truncates at a certain radius and evaporates into the inner hot coronal flow which fills up the inner part of the accretion flow. Such flow in this source act as the birthplace of the cyclo-synchrotron emission.

Thus SALT BVIT data helped to show that the optical flares of the order of a few seconds to a few tens of seconds may not originate from the reprocessing of the outer accretion disk, but rather that the self-absorbed cyclotron process associated with the hot magnetised inner accretion flow provides a convincing explanation of the optical emission.



SALT/SALTICAM R filter image of the field near the black hole X-ray transient GS 1354–64. The black hole source is marked with `1354' while the position of comparison stars are marked with `A' to `E'.



The raw optical lightcurve of GS 1354–64 (top panel), background and atmospheric variation corrected lightcurve (middle panel), and background corrected comparison star lightcurve (bottom panel) as observed by the BVIT instrument.

Pahari, M., et al, 2017/07, MNRAS 469, 193: Simultaneous optical/X-ray study of GS 1354–64 (=BW Cir) during hard outburst: evidence for optical cyclo-synchrotron emission from the hot accretion flow

RECOVERY OF A NOVA SPOTTED BY ANCIENT KOREANS ILLUMINATES MANY STAGES OF A STAR SYSTEM'S LIFE CYCLE

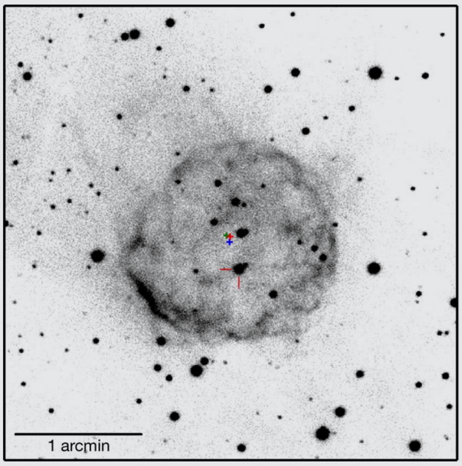
On a cold March night in Seoul almost 600 years ago, Korean astrologers spotted a bright new star in the tail of the constellation Scorpius. It was seen for just 14 days before fading from visibility. From these ancient records, modern astronomers determined that what the Royal Imperial Astrologers saw was a nova explosion, but they have been unable to find the binary star system that caused it – until now. A new study published in the journal Nature by Michael Shara from the American Museum of Natural History together with Krystian Iłkiewicz and Joanna Mikołajewska from the Copernicus Astronomical Center of the Polish Academy of Sciences and 13 coauthors, pinpoints the location of the old nova, which now undergoes smaller-scale "dwarf nova" eruptions. This is the first nova that has been recovered with certainty based on the Chinese, Korean, and Japanese records of almost 2,500 years.

The study, based on observations from SALT and smaller telescopes at the South African Astronomical Observatory as well as the Las Campanas Observatory, supports the idea that novae go through a very long-term life cycle after erupting, fading to obscurity for thousands of years and then building back up to become full-fledged novae once more. A nova is a colossal hydrogen bomb produced in a binary system where a star like the sun is being cannibalised by a white dwarf – a dead star. It takes about 100,000 years for the white dwarf to build up a critical layer of hydrogen that it steals from the sun-like star, and when it does, it blows the envelope off, producing a burst of light that makes the star up to 300,000 times brighter than the sun for anywhere from a few days to a few months.

For many decades, Shara and other scientists have tried to pinpoint the position of the star which was a source of the nova eruption in 1437. In the recent study the area of search for candidates was expanded thanks to a new interpretation of the ancient records. As a result, the nova remnant, which is the ejected nova shell with the cataclysmic binary near to its centre was found (see figure). The finding was confirmed with another kind of historical record: a photographic plate from 1923 taken at the Harvard Observatory station in South Africa. The position of the binary in 1923, compared to the current position, made it possible to measure the velocity with which the star moves on the sky. Tracing back this motion to 1437 placed the binary right in the centre of the shell (see figure). The motion of the star is like a clock, which proves that this object is responsible for the outburst recorded by the Korean astrologers. Other photographic plates from the 1940s helped reveal that the system is now a dwarf nova, indicating that so-called "cataclysmic binaries" – novae, novae-like variables, and dwarf novae – are one and the same, not separate entities as has been previously suggested. After an eruption, a nova becomes "nova-like", then a dwarf nova, and then, after a possible hibernation, comes back to being nova-like, and then a nova, and does it over and over again, up to 100,000 times over billions of years.

To get a better look at the present state of the binary system, Joanna Mikołajewska led a project to obtain several SALT/RSS spectra of the binary and the shell. These data allowed the team to identify the white dwarf companion and to determine its temperature and distance, to constrain the binary components' masses, as well as to estimate the temperature, density and mass of the shell.

The challenge in understanding the evolution of these binary stars is the life-cycle of a nova which is hundreds of thousands of years. We simply have not been around long enough to see a single complete cycle. The breakthrough was to be able to reconcile a 580-year-old Korean recording of a nova event with a specific dwarf nova and nova shell that we see in the sky today.

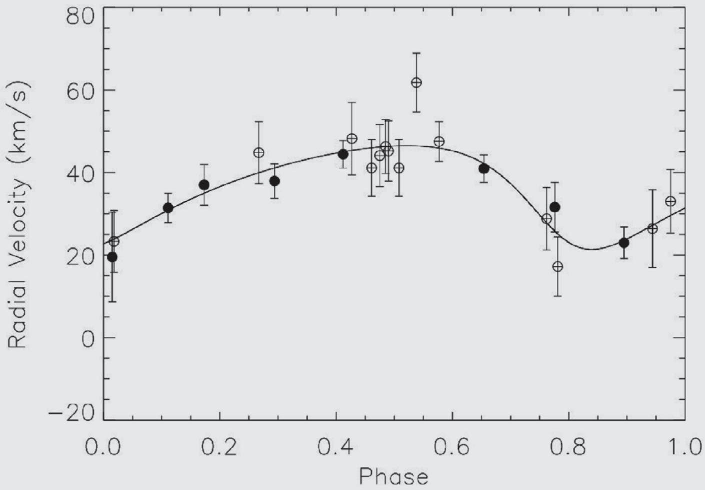


This Hα image was taken at Las Campanas observatory North is up and east is to the left. The location of the cataclysmic variable in 2016 is indicated with red tick marks. Its proper motion places the AD 1437 cataclysmic variable at the red plus sign. The position of the centre of the shell in 2016 and its deduced position in 1437 are indicated with blue and green plus signs, respectively.

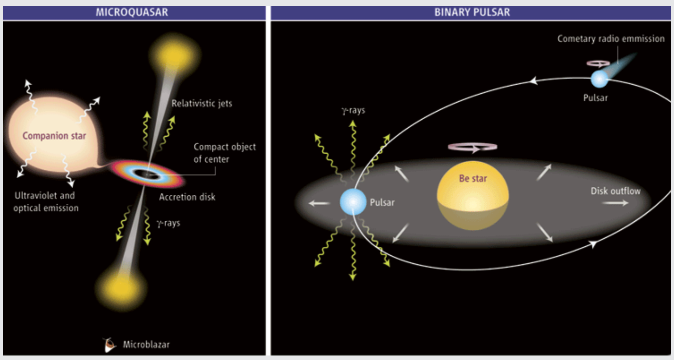
Shara, M.M., et al., 2017/08, Nature 548, 558: Proper-motion age dating of the progeny of Nova Scorpii AD 1437

THE ORBIT OF THE GAMMA-RAY BINARY 1FGL J1018.6–5856

Gamma-ray binaries (GRBis) are an intriguing small subclass of high mass X-ray binaries that emit radiation across the whole electromagnetic spectrum. These systems comprise a massive O or Be star and a compact object. Apart from one system, PSR B1259–63, the nature of the compact object in GRBis remains an open question as it is challenging to distinguish between a neutron star and a black hole. The uncertainty in the nature of the compact object gives rise to two competing models that try to explain the multi-wavelength emission: the microquasar model and the pulsar wind model. In the microquasar model, the compact object (either a neutron star or black hole) accretes matter from its massive companion, a fraction of which gets ejected via relativistic jets which provide a site for particle acceleration and multi-wavelength emission. Alternatively, in the pulsar wind model, the relativistic wind from a rapidly rotating young pulsar interacts with the slow-moving wind/disc from the companion, producing a shock where particles are accelerated, resulting in multi-wavelength emission.



Best-fitting curve to the radial velocities of the He II lines. The unfilled circles are from the literature and the filled circles are the new SALT/HRS measurements.



The microquasar and pulsar wind model scenarios proposed for γ-ray binaries. Credit: Mirabel (2006).

Ph.D. student Itumeleng Monageng at SAAO, together with South African collaborators, decided to address this question by studying another GRBi system, 1FGL J1018.6–5856, which consists of an O star and an unknown compact object in a 16.6 day orbit. Since its discovery at GeV energies using *Fermi*-LAT, the other orbital parameters of J1018 have been elusive. Previous attempts of deriving the orbital parameters using radial velocity techniques have been frustrated by poor phase coverage and low signal-to-noise spectra. Monageng and his co-authors obtained SALT HRS spectra in medium resolution mode and derived from the measured radial velocities for the first time the geometry of the system, in particular, an eccentricity of $e = 0.31 \pm 0.16$. The range of possible masses for the compact object demonstrates that the companion is likely a neutron star and that the pulsar wind model is favoured in this system.

Monageng, I.M., et al, 2017/09, ApJ 847, 68: The orbit of the γ-ray binary 1FGL J1018.6–5856

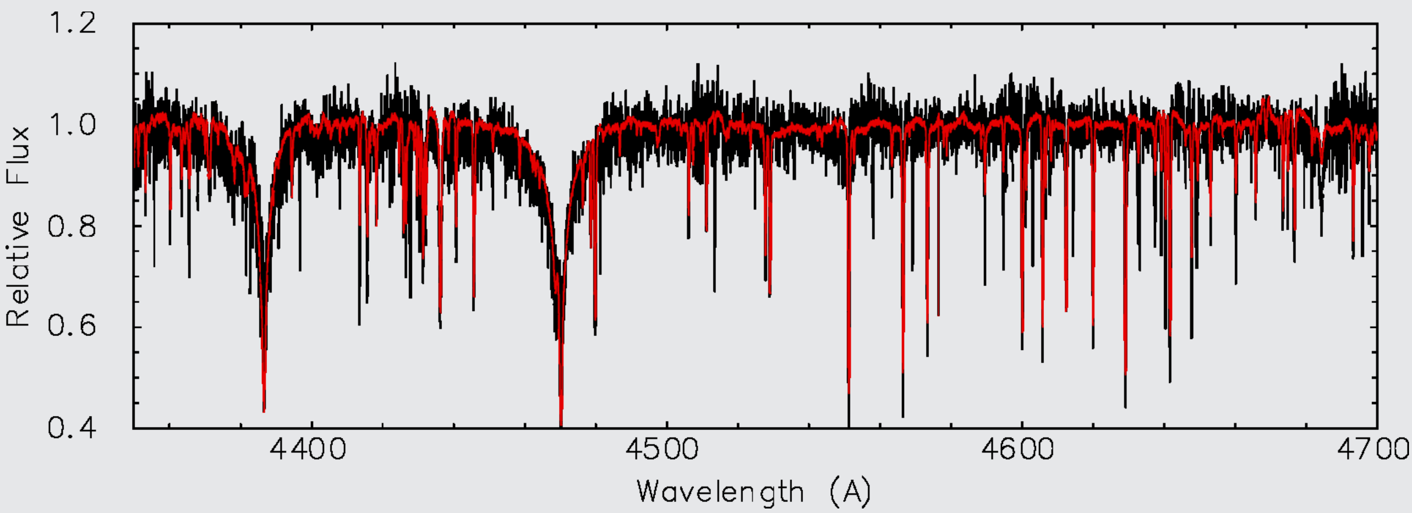
GALEX J184559.8-413827: SALT IDENTIFIES A NEW EXTREME HELIUM STAR

Extreme helium stars represent a small group of low-mass supergiants. They have spectral types equivalent to A and B, but with very weak or absent Balmer absorption lines. First recognised in the 1940s, their number grew to around 17 by the early 1980s, with most discovered from low-resolution spectroscopic surveys of faint blue stars. There are strong links between extreme helium stars and the cooler and very variable R Coronae Borealis stars; the most promising explanation for the extraordinary surface composition of both groups is that they were formed from the merger of a carbon-oxygen and a helium white dwarf – a rare event that would have produced a strong burst of gravitational waves in the Galaxy.

Up to the 1970s, faint meant 13th magnitude. Most extreme helium stars are sufficiently luminous that to have an apparent magnitude greater than 14 would place them beyond our own Galaxy. Therefore, it is not surprising that subsequent surveys of faint blue stars discovered no new extreme helium stars. What these surveys have found, in abundance, are hot subdwarfs, the majority of which are hydrogen-rich. Some 10 per cent show strong helium and weak or absent hydrogen lines. Most lie close to the helium-main sequence, with ionised helium lines prominent in the spectrum. It is suspected that these are the product of mergers between two helium white dwarfs.

Cool helium-rich stars identified by having weak ionised helium lines formed one focus of a survey of chemically-peculiar hot subdwarfs with SALT/HRS that was conducted by Simon Jeffery from Armagh Observatory in Northern Ireland. The spectrum of one star, GALEX J184559.8–413827, stood out from the sample, having a forest of lines due to ionised nitrogen. Over-familiarity with the spectrum of another star, the pulsating helium star V652 Herculis, triggered an instant recognition that J1845 might not be a hot subdwarf but, rather, a new low-luminosity extreme helium star, the first to be found for nearly 40 years.

J1845 is spectroscopically similar to V652 Herculis, one of a handful of low-luminosity extreme helium stars which has been studied in great detail, and whose decreasing pulsation period and surface chemistry point to an origin in a helium white dwarf merger. The discovery of J1845 adds substantial evidence for a sequence of post-merger stars evolving to become extremely helium-rich subdwarfs.

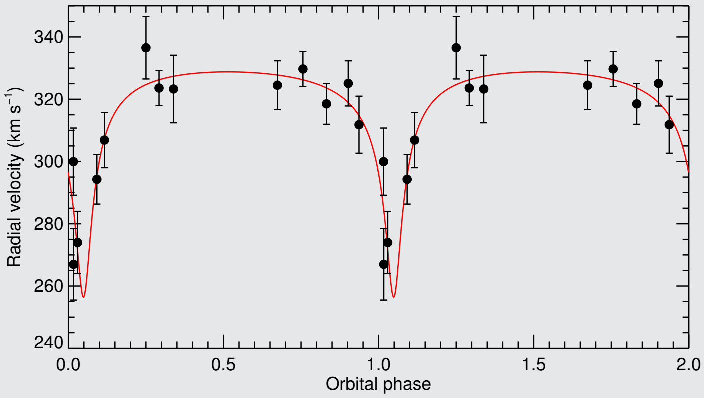


Part of the renormalised SALT/HRS spectrum of GALEX J184559.8–413827 (black) compared with the median spectrum of V652 Herculis near maximum radius.

Jeffery, C.S., 2017/09, MNRAS 470, 3557: GALEX J184559.8–413827: a new extreme helium star identified using SALT

CONSTRAINTS ON THE SYSTEM PARAMETERS OF THE BE/X-RAY BINARY A0538–66

A spectroscopic and photometric campaign was conducted by Andry Rajoelimanana from the University of Free State and a team of local and international researchers to study the long-term properties of the most extreme Be/X-ray binary A0538–66. Using the decade long photometry provided by the MACHO and OGLE–IV projects and high-resolution SALT/RSS spectroscopy, they constructed an orbital radial velocity curve from which the orbital parameters were inferred, revealing an eccentricity of 0.72. This makes A0538–66 one of the most highly eccentric X-ray binaries known in the Universe. Furthermore, the mass function indicates that the donor must be significantly undermassive for its spectral type, unless the neutron star far exceeds the canonical 1.44 Solar masses. Both the broad-band and high-resolution spectra from RSS confirm the optical companion as a B1 III star.

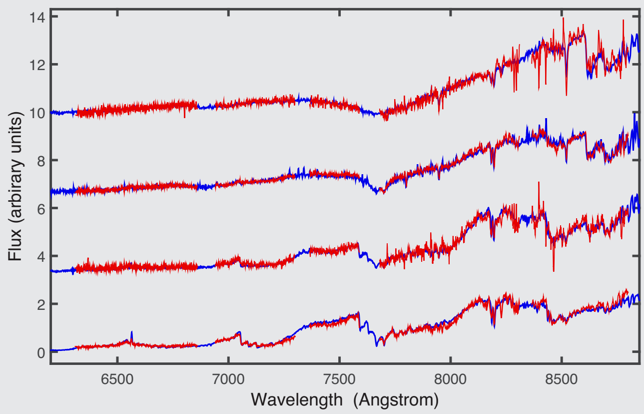


Radial velocity curve of the Helium lines for A0538-66. The red line shows the best-fitting radial velocity.

Rajoelimanana, A.F., et al., 2017/02, MNRAS 464: 4133: Orbital and superorbital monitoring of the Be/X-ray binary A0538–66: constraints on the system parameters

SALT SPECTRA OF ULTRACOOL DWARFS

Many of the closest stars to the Sun are very low mass, ultracool dwarfs with spectral types M7 or later. These stars are extremely faint or invisible at optical wavelengths, but can be readily studied at infrared wavelengths. In their paper, Chris Koen from the University of Western Cape and his South African team used SALT/RSS to take spectra of 81 ultracool dwarfs at red and infrared wavelengths. An automated classification scheme was developed to classify the spectra based on fitting template spectra from the literature. A comparison with classifications based on spectral indices was also performed. The figure shows some examples of SALT/RSS spectra and their template fits. A total of 32 new classifications were obtained in this study and alternative classifications were presented for 32 previously classified ultracool dwarfs. In some cases, where repeat spectra were obtained, variability in the Hα emission line due to flares could be detected. This work demonstrates the powerful niche capability of SALT to conduct spectroscopy for large numbers of optically faint targets spread evenly across the sky.



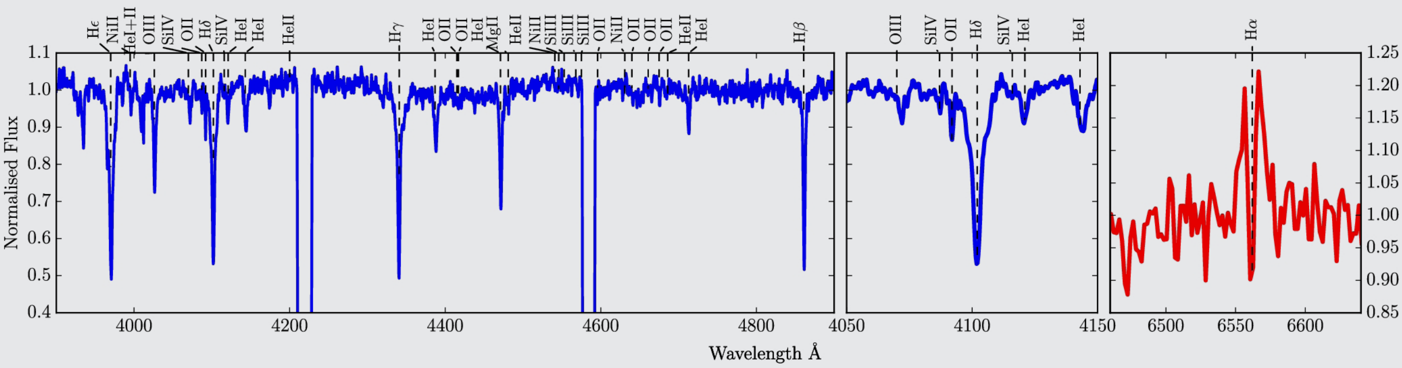
Examples of the fits of SALT/RSS spectra (red) to templates (blue). From top to bottom, 2M 2252–1730 (spectral type L5); 2M 0128–5545 (L3); 2M 1523–2347 (L0); and 2M 1308–4925 (M7).

Koen, C., et al., 2017/03, MNRAS 465, 4723: Optical spectra of ultracool dwarfs with the Southern African Large Telescope

SXP 7.92: A RECENTLY REDISCOVERED BE/X-RAY BINARY IN THE SMALL MAGELLANIC CLOUD

Liz Bartlett from the University of Cape Town and collaborators used SALT as well as other telescopes to study the Be/X-Ray binary (BeXRB) SXP 7.92 that underwent an outburst in 2013. The normalised RSS/SALT spectrum (shown in blue in the figure) was used to classify the object as a BIVe star with an uncharacteristically narrow Balmer series. The Ha emission line in particular has a distinctive shell profile, that is, a deep absorption core embedded in an emission line, indicating that the star is likely viewed nearly edge on.

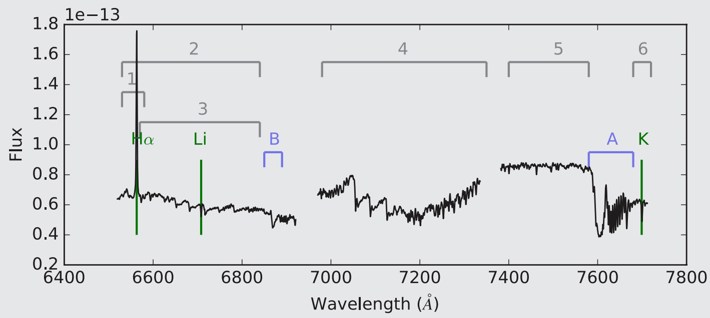
The SALT spectrum (left, with a zoom in the middle panel) shows atomic transitions relevant to spectral classification. The spectrum of the Hα emission line (right) was obtained with the NTT at La Silla in Chile.



Bartlett, E.S., et al., 2017/04, MNRAS 466, 4659: SXP 7.92: A recently rediscovered Be/X-ray binary in the Small Magellanic Cloud, viewed edge on

YOUNG STARS WITH SALT

Adric Riedel from the American Museum of Natural History and colleagues examined 79 nearby red dwarf stars in 77 star systems that were suspected to be under 600 Myr old. Using SALT's RSS, they were able to set up observations that allowed identification of chromospheric activity, surface gravity, youth, radial velocity, and spectral types, all from the same instrument setup. The observations allowed them to confirm a multitude of new young stars within 100 parsecs of the Sun, including one new member of the 10 Myr old TW Hydra moving group, a new member of the rarely-studied 20 Myr old 32 Orionis moving group, and nine new members of the 45 Myr old Tucana–Horologium moving group.



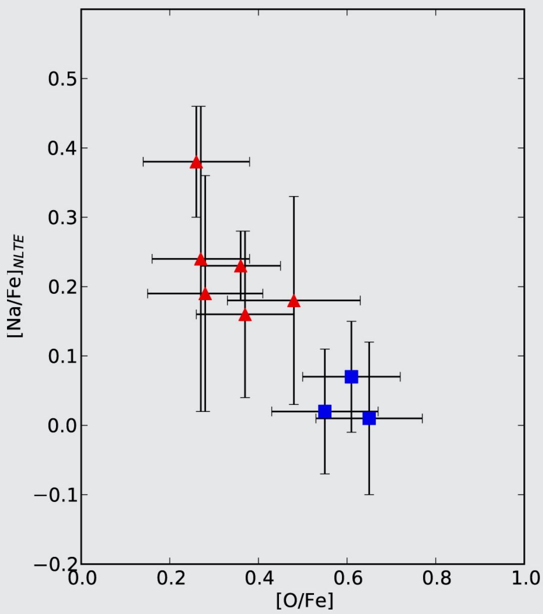
The RSS M dwarf spectra, like the one shown here for TWA 8A (a known member of TW Hydra), contain the Hα 6563Å line (activity), the lithium 6708Å doublet (youth), and the potassium 7699Å line (surface gravity). Also shown are six regions considered in the radial velocity measurements, and the atmospheric A and B band regions used to correct for wavelength calibration errors.

Riedel, A.R., et al. 2017/05, ApJ 840, 87: Young stars with SALT

ABUNDANCES OF THE GLOBULAR CLUSTER NGC 6681

Erin O'Malley and Brian Chaboyer from Dartmouth College, together with Alexei Kniazev (SALT) and Andrew McWilliam (Carnegie Observatories) used the high-resolution spectrographs at Magellan and SALT to obtain high signal-to-noise spectra of nine red giant branch stars in the globular cluster NGC 6681 and perform the first detailed abundance analysis of stars in this cluster. They confirmed cluster membership for these stars based on consistent radial velocities of 214.5 ± 3.7 km/s and find a mean [Fe/H] = -1.63 ±0.07 dex and [α/Fe] = 0.42 ± 0.11 dex.

Additionally, they found the existence of a sodium-oxygen (Na–O) anti-correlation in NGC 6681 and identify two populations of stars with unique abundance trends. This is similar to what has been observed in many other globular clusters, and is indicative of NGC 6681 containing two distinct stellar populations. With the use of HST photometry, O'Malley and her colleagues were able to identify these two populations as discrete sequences in the cluster colour-magnitude diagram.



Correlation between sodium and oxygen. Stars with a typical halo abundance ratio are indicated by blue squares while the red triangles indicate stars whose abundances are indicative of second population which has been enriched in sodium and depleted in oxygen.

O'Malley, E.M., et al, 2017/09, ApJ 846, 23: High-resolution spectroscopic abundances of red giant branch stars in NGC 6681

SCIENCE HIGHLIGHTS:
ONGOING RESEARCH

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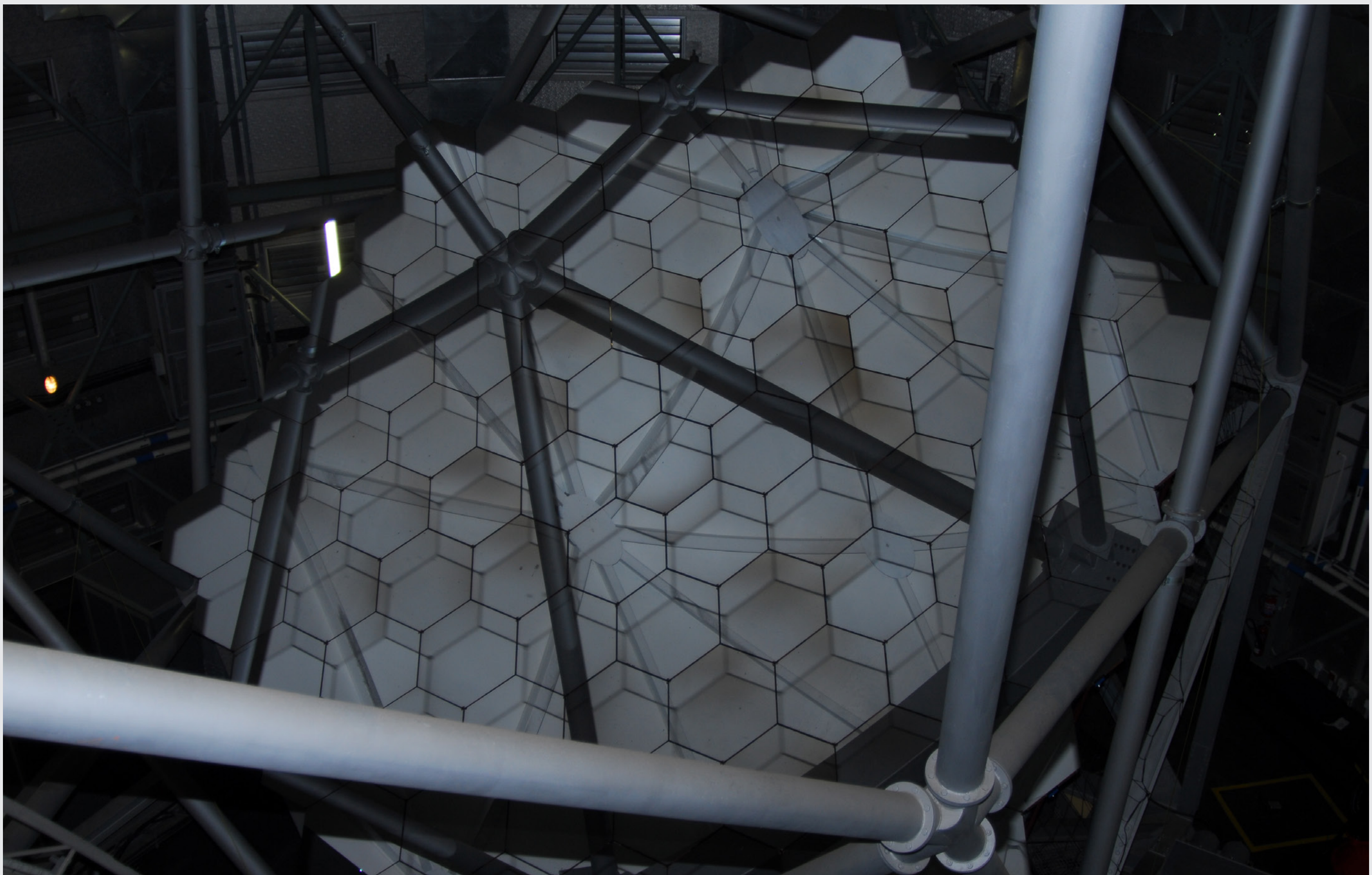

A number of exciting SALT science projects are either close to being published or are longer-term projects that may lead to publications on selected objects of interest, awaiting completion of the final science goals. The following section gives an overview of a small selection of these.

There is only one Large Science Proposal at SALT to date: "Observing the Transient Universe", a target-of-opportunity project led by David Buckley at SAAO, is currently in its forth (out of five) semester. The international team comprises more than 40 Co-Is, and telescope time is charged to four different partners (RSA, UKSC, Poland, IUCAA). Five Ph.D. and three M.Sc. projects are associated with this programme. SALT is the ideal telescope for a transient follow-up project: its queue scheduling provides the rapid response required (witin days, or even hours) and having the full suite of instruments available at all times allows the observer to quickly switch between them, depending on the science requirements. Typical object classes (with the fraction of observing time to date in parentheses) include X-ray/γ-ray transients, including low and high mass X-ray binaries as well as γ-ray bursts (37%), cataclysmic variables from MASTER and ASASSN optical transient detection systems (13%), novae (11%), optical counterparts to transients discovered from the OGLE, Gaia and ASASSN surveys (31%) and Blazars (8%). By the end of 2017, 900 kiloseconds of observing time had been spent on this programme. As a result, the first four papers have been published in 2017 (Kupfer et al., Townsend et al., Böttcher et al., Mata Sánchez et al.), with at least seven more submitted or presently ready for submission. At least seven conference presentations were based on these observations, and more than 15 Astronomer Telegrams have been issued.

While Large Science Proposals demand more than 150 observing hours, another proposal class, the long-term proposals, stay under this limit but are conducted over several semesters (or observing seasons). Four of these have been carried over into 2017 from previous semesters, and 23 have started in the 2017 semesters. The oldest of these is the SALT gravitational lensing legacy survey led by Stephen Serjeant of The Open University (UKSC), which requests time from three different partners (RSA, UKSC, RU). It started in the second semester of 2015 and with more than 320 kiloseconds observing time to date it requires just one more semester for completion. The goal of the project is to map galactic dark matter distributions using strong gravitational lensing, aiming to measure 500 lens redshifts from Herschel surveys. This project represents a synergy between SALT and other large, current and future, observatories: ALMA, SKA and the E-ELT. In March 2017, Mattia Negrello reported on the team's preliminary results.

Two other SALT programmes are harbingers of the future which will see the growing need for optical observations of radio sources detected by the upcoming SKA and its precursors. Both of the radio projects associated with these SALT programmes search for the 21-cm neutral hydrogen (HI) line emission in distant galaxies: the CHILES project is currently being conducted with the Very Large Array, and LADUMA, which will start in 2018 when the SKA-precursor MeerKAT comes online. The optical redshifts will allow stacking of HI spectra and thus the derivation of mean HI properties of galaxies at intermediate redshifts (z ~ 0.2 and 0.4/0.5, respectively) which have not yet been probed by HI observations. The PIs are Eric Wilcots (University of Wisconsin-Madison) and Sarah Blythe (UCT), respectively.

"Deeper, Wider, Faster: Confirming the fastest transients in the Universe with SALT" is another target-of-opportunity follow-up programme. It uses DDT time and is led by Jeff Cooke from the Swinburne University of Technology in Australia. The DWF project itself involves over 20 major observatories world-wide and in space to perform simultaneous, deep, wide, and fast-cadence observations. The data are processed and analysed within seconds, and telescopes like SALT are triggered for rapid follow-up spectroscopy and imaging of the events before they fade. The project also involves later-time observations to study the host galaxies and to observe longer duration events that are associated with fast bursts.

Ryan Hickox's research group at Dartmouth College has been carrying out multiple projects with RSS, studying AGN and quasars. One is a continuation of their ongoing programme to follow up candidates of heavily obscured quasars, selected by WISE and SDSS, with optical spectroscopy. They have found that a majority of the candidates are indeed heavily obscured, luminous AGNs. These samples are used to study the physical properties of obscured quasars and their spatial clustering. The latest sample has been analysed by fourth-year undergraduate Raphael Hviding, who also took part in the Dartmouth Foreign Study Program to Cape Town in 2016.

Valentina Cracco from the University of Padova in Italy, together with Marina Orio (University of Wisconsin and INAF-Padova, Italy) and collaborators from UW and SAAO, is studying the Be stars associated with four recently discovered X-ray sources (Suzaku J0105-72, XMMU J010147.5-715550, XMMU J052016.0-692505 and MAXI-J0158-744). They are all high mass X-ray binaries, but unlike the vast majority of the known Be high-mass X-ray binaries, which have a neutron star as the companion, these four have a massive white dwarf as companion instead. The team maps the emission lines of these four Be stars every few weeks to follow the orbital periods which are expected to be of the order of a few months. They then attempt to derive the structure, size and geometry of the excretion disk of the B stars, through which the white dwarfs are thought to be accreting considerable amounts of material. Thus, these white dwarfs may be growing towards the Chandrasekhar mass limit, in which case they would ultimately explode as Type Ia supernovae.

Leonardo Tartaglia from the Steward Observatory in Arizona (USA) and his team have used SALT/RSS for follow-up observations of the highly obscured Type II SN 2016ija/DLT16am, the first supernova discovered by the ongoing one-day cadence D<40 Mpc (DLT40) survey. This survey is scanning the nearby Universe in search of young supernovae to capture them within a of day their explosion. SN 2016ija-DLT16am is one of the most highly obscured supernovae discovered so far (with E(B-V)=1.5 mag); spectra collected with smaller telescopes showed little or no flux at wavelengths shorter than 6000 Å, but the higher signal-to-noise ratio of the SALT spectrum at bluer wavelengths has been crucial for inferring the temperature evolution during the very early phases, and hence for estimating the radius of the progenitor star.

SCIENCE HIGHLIGHTS:
STUDENT PROJECTS

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In compliance with SALT's strategic objective of Human Capital Development, a large number of projects involve students or are initiated by students. Some examples of ongoing student projects are presented here. Projects with publications in 2017 can be found in the research section.

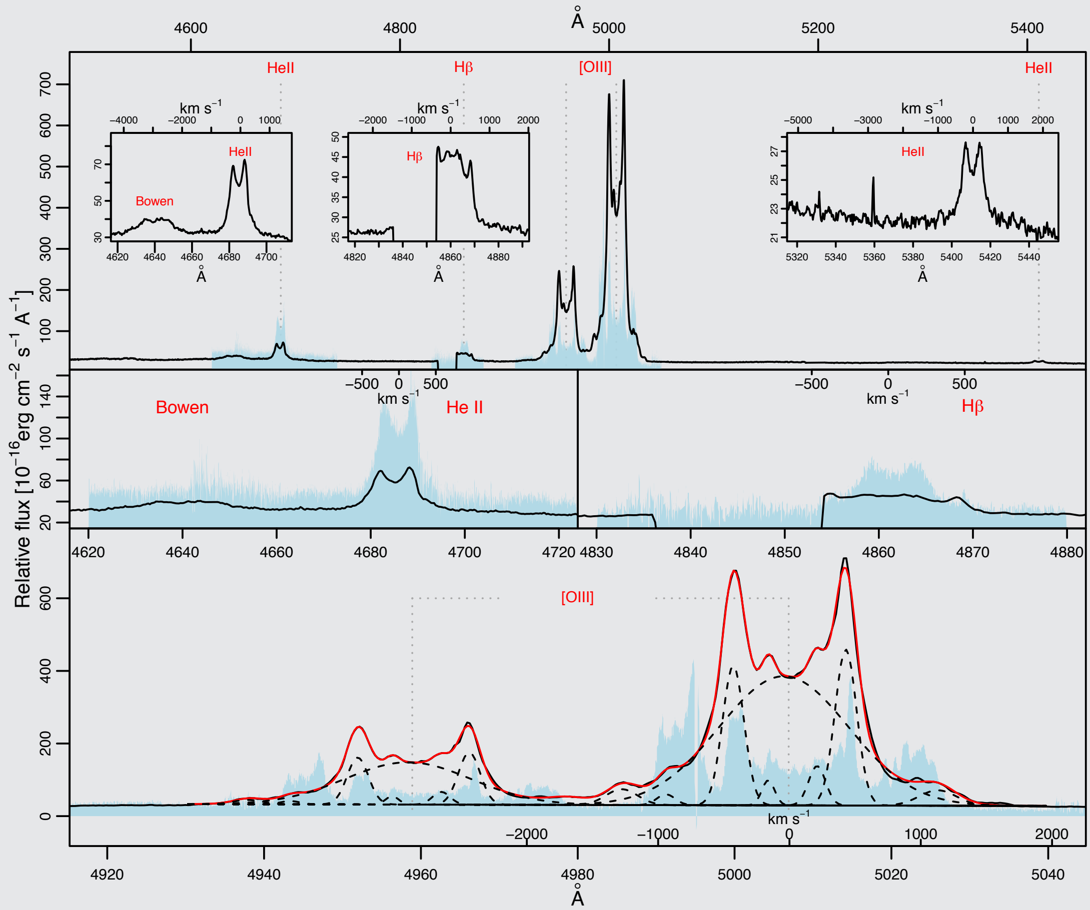
An exciting project in progress is led by Dartmouth College graduate student Wei Yan who analyses NuSTAR hard X-ray observations of heavily obscured systems. These were previously identified in a SALT campaign conducted by Ryan Hickox's group at Dartmouth College, which was published in 2014. Wei Yan has found evidence for very heavy nuclear obscuration in these sources.

Yssavo Camacho is a third year Ph.D. student at Rutgers working on understanding white dwarf supernova explosions. Her focus is the study of the peculiar class of Type Iax supernovae, including SALT spectroscopy of objects like SN 2014dt in M61.

Kyle Dettman is a third year Ph.D. student at Rutgers studying Type Ia supernovae as part of the Foundation survey to create a new anchor sample of low-redshift SN Ia for cosmology. He uses SALT spectroscopy to classify new supernovae, to get their host galaxy's redshift, and to study potential correlations between supernova ejecta velocity and photometric properties.

Igor Andreoni is a Ph.D. student at Swinburne University of Technology and is expected to graduate in mid-2018. His project is the "Deep multi-wavelength exploration of the fast transient Unvierse". He was also involved in the GW170817 observations with SALT which resulted in one of the four SALT papers on this subject published in October 2017.

Ph.D. student Polina Zemko from Padova University (supervisor Marina Orio from University of Wisconsin and INAF-Padova) studies optical spectra of novae as they return to quiescence; the spectra were taken with SALT/RSS and in one case with the HRS. The figure shows the comparison between the RSS spectrum of the recurrent nova T Pyx, taken in 2012, together with the HRS spectrum from 2016. The more recent lines show a very complex profile, indicating the early fragmentation and clumpiness of the shell of this nova.

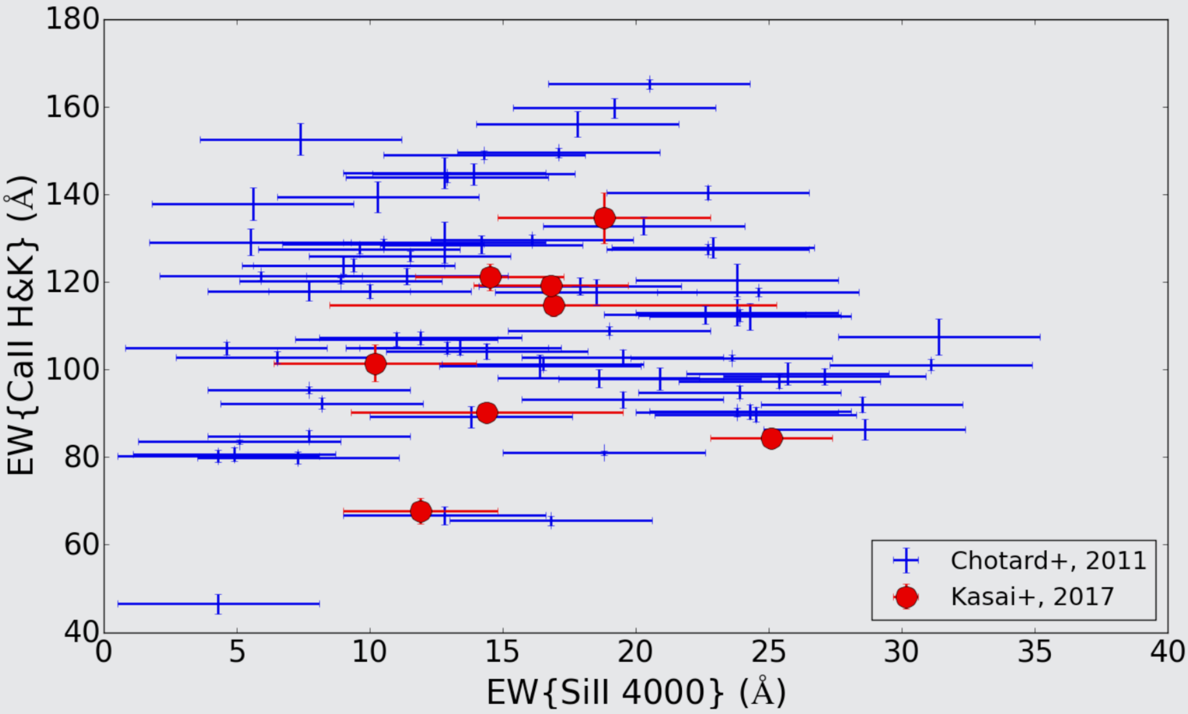


Comparison of an RSS spectrum from 2012 (black line) and an HRS spectrum from 2016 (light blue) of T Pyx.

SALT SPECTROSCOPY AND CLASSIFICATION OF SUPERNOVA SPECTRA USING BAYESIAN TECHNIQUES

Eli Kasai from the University of Cape Town (supervisors Bruce Bassett and Steve Crawford, SAAO) obtained his Ph.D. in 2017 using SALT/RSS data in his thesis. His goal was to develop a new Bayesian supernova spectrum classifier (called SuperNovaMC) to address limitations with existing algorithms. SuperNovaMC simultaneously finds the best supernova and host galaxy fits using Bayesian model selection. Fitting the entire spectrum with Monte Carlo Markov Chain methods allows estimation of the entire parameter posterior distributions and hence a principled statistical analysis even at low signal-to-noise.

After extensive testing of SuperNovaMC against simulations and literature data, Eli used his new algorithm on 36 supernova candidates from the Dark Energy Survey for which he and his team obtained SALT/RSS spectra; 20 of these turned out to be Type Ia supernovae. He used a subsample of these to perform equivalent width measurements of two of the Type Ia supernova spectral features: Ca II H&K and Si II 4000 Å. A comparison with a similar study conducted at lower redshifts ($z < 0.1$) showed the two sets to be consistent, suggesting no redshift evolution in the equivalent widths of the two spectral features occurred in the redshift range $0.1 < z < 0.3$.



Equivalent width measurements of Si II 4000 Å vs Ca II H&K features for 8 SN Ia spectra presented in the thesis (red), compared to the same measurements performed on a sample of published 76 low-redshift ($z < 0.1$) SN Ia spectra (blue).

Eli Kasai, University of Cape Town, Ph.D. 2017

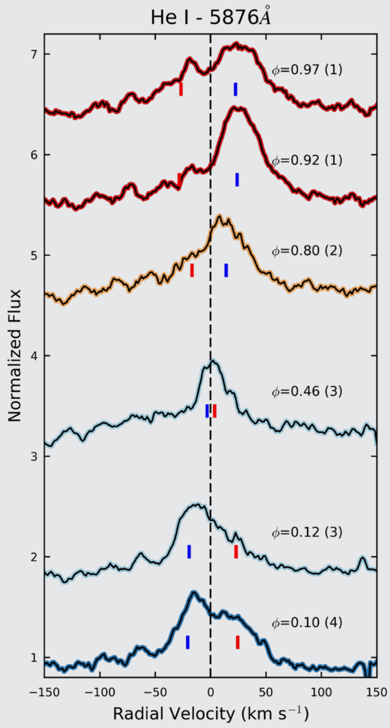
Hα LONGSLIT OBSERVATIONS OF CHILES GALAXIES

Over the past three observing semesters, graduate student Julie Davis and faculty member Eric Wilcots from the University of Wisconsin-Madison have collected RSS longslit data for a sample of eleven galaxies in the COSMOS field. These galaxies are a selection of the nearest ($z < 0.1$) galaxies in the on-going COSMOS HI Large Extragalactic Survey (CHILES), a 1000-hour integration of a single pointing in the COSMOS field out to $z=0.45$ using the Very Large Array. The exceptional mass sensitivity and angular resolution of CHILES enables HI 21-cm morphological and kinematic investigations of unprecedented detail at this distance. The SALT longslit data gives Julie a complementary picture of the ionized gas kinematics in these galaxies through Hα emission. Preliminary analysis of both the 21-cm and the Hα emission shows potential interesting properties such as alignment of HI holes and regions of Hα emission, peculiar kinematics in galactic central regions, and misalignment of the optical and HI major kinematic axes.

Julie Davis, graduate student,University of Wisconsin-Madison, USA

PROPERTIES OF THE PROTOPLANETARY DISKS IN YOUNG BINARIES

Ph.D. student Ben Tofflemire from the University of Wisconsin-Madison wants to determine how binary orbital dynamics affect the distribution and flows of protoplanetary disk material in young binaries, with the ultimate goal to better understand how star and planet formation differ in binary systems. For this purpose he has obtained SALT/HRS spectra of the T Tauri binary TWA 3A. He uses the accretion-tracing emission line He I 5876 Å to determine which star in the accreting binary is preferentially receiving material from a circumbinary accretion disk. Near periastron the line's strength and width increase due to elevated accretion. At these times the line's velocity centroid consistently falls at the primary star's velocity (shown with a blue vertical line for each observation in the figure), suggesting the primary is accreting most of the material. This is in contrast to most numerical simulations which imply that the secondary should be the primary accretor. If this system's behavior is representative of younger binaries, it may carry important implications for the orbital evolution of young binaries.



The plot shows 6 continuum normalized SALT/HRS spectra of He I 5876 Å obtained over three binary orbital cycles. The orbital phase and cycle are given to the right (the orbital cycle is also denoted by the line color). The primary and secondary stellar radial velocities are shown by blue and red vertical dashes, respectively. The emission in the middle spectrum, near apastron, is likely chromospheric and an example of the line's intrinsic strength in the absence of accretion.

Ben Tofflemire, Ph.D. student, University of Wisconsin-Madison, USA

SCIENCE HIGHLIGHTS:

SALT CONFERENCE

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SALT AMONG THE CONSTELLATIONS OF VERY LARGE TELESCOPES

7–9 June in Kazimierz Dolny, Poland

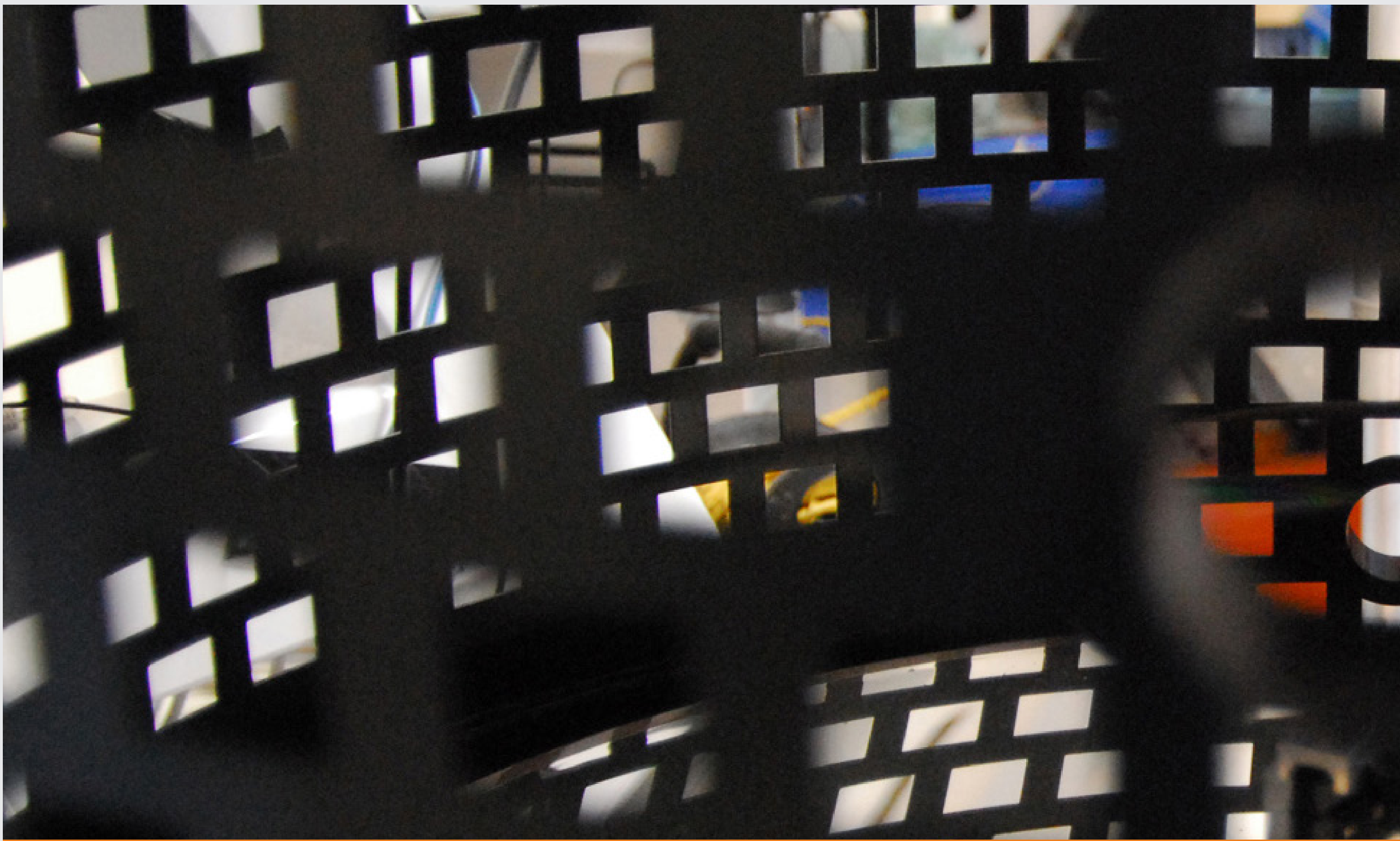
A SALT science workshop entitled "SALT among the constellations of very large telescopes" was held at the delightful Folwark Walencja hotel in the historic and extremely picturesque Polish town of Kazimierz Dolny. More than 50 participants attended the three-day conference that immediately followed the June SALT Board meeting which was held in the same venue. As with the Stellenbosch SALT workshop in 2015, the focus of the meeting was on presenting scientific results obtained with SALT and this provided a wonderful opportunity for members of the SALT community, specifically users from across the partnership and members of the SALT Operations team, to connect in person and share information.

Petri Väisänen, the head of SALT Astronomy Operations, began the proceedings with a comprehensive overview of SALT and its current capabilities. This was followed by a humbling update on the numerous facilities and developments at ESO, by Rob Ivison – ESO's Director for Science. SALT Board chairman Michael Shara then drew on Martin Harwit's remarkable *Cosmic Discovery* book for his excellent big-picture talk about leveraging discovery spaces in astronomy in order to permit fundamentally new discoveries. The rest of the meeting involved a wide range of talks, grouped into four major sections: transients; binary stars; star formation, planets and interstellar medium; galaxies, QSOs and blazars.

Along the way, Steve Crawford presented a radical instrumentation concept that could revolutionise the way SALT operates in years to come. The notion of having a number of "mini trackers" patrolling the 12-degree field of the SALT primary mirror immediately set creative minds whirring. An extra session was added at the end of the second day to allow participants to briefly present many exciting new science results obtained since the abstract submission deadline for the workshop. Besides giving a great talk on "MeerKAT, MeerLICHT and SALT", Patrick Woudt (Head of the Astronomy department at the University of Cape Town) also produced a fantastic conference summary that captured all of the highlights from the various results presented. The summary also placed SALT – and indeed all of astronomy in Southern Africa – in context "among the constellations of very large telescopes", which Patrick aptly dubbed "our modern-day cathedrals of science".

So productive was the workshop, it has since been proposed that these sorts of gatherings become a regular fixture on the SALT calendar, every 18 months to two years. The only concern is that an extremely high organisational bar has been set by Joanna Mikołajewska and her team that made the workshop in Kazimierz Doly such a success; it will be a tough act for others to follow!

OPERATIONS



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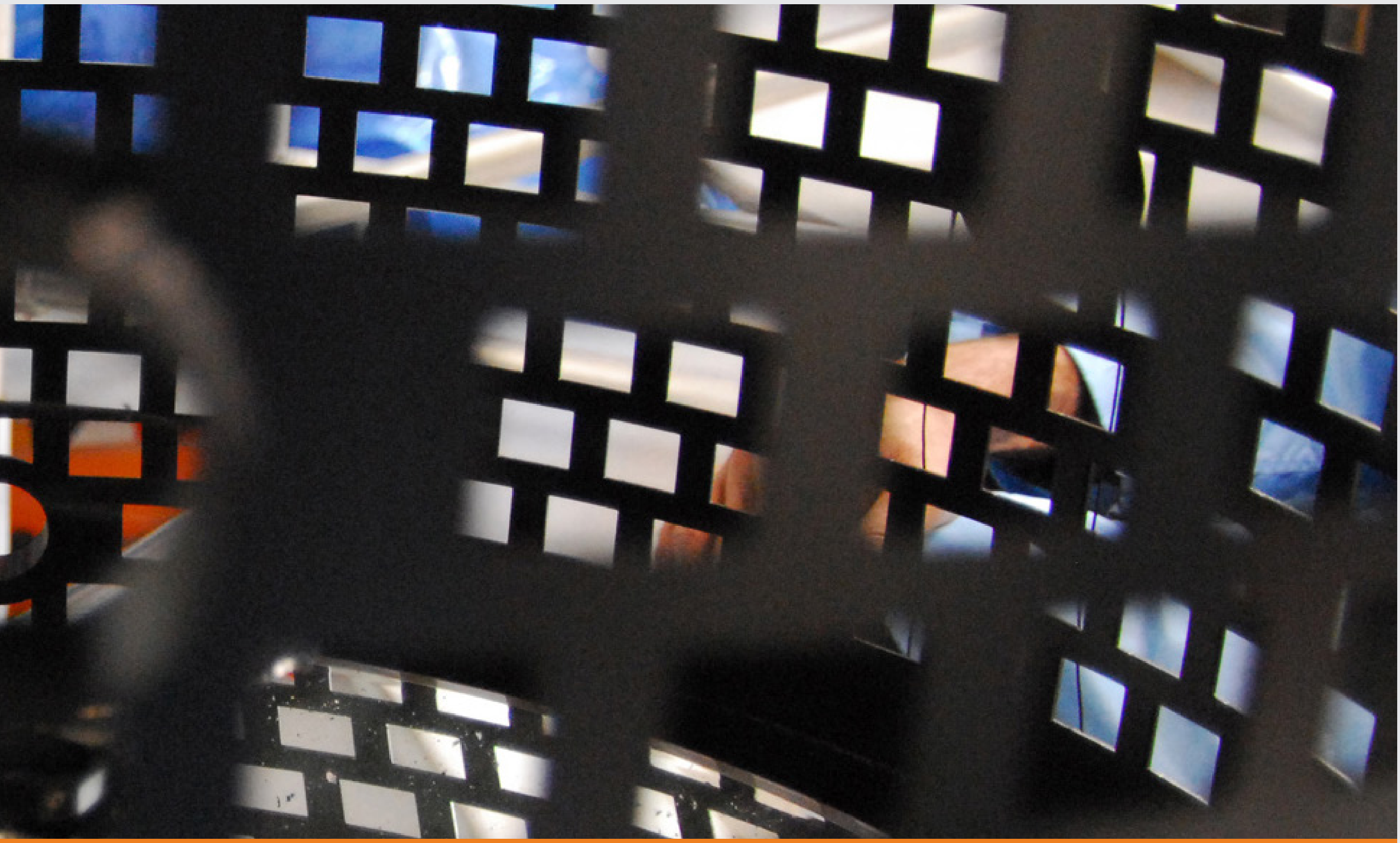
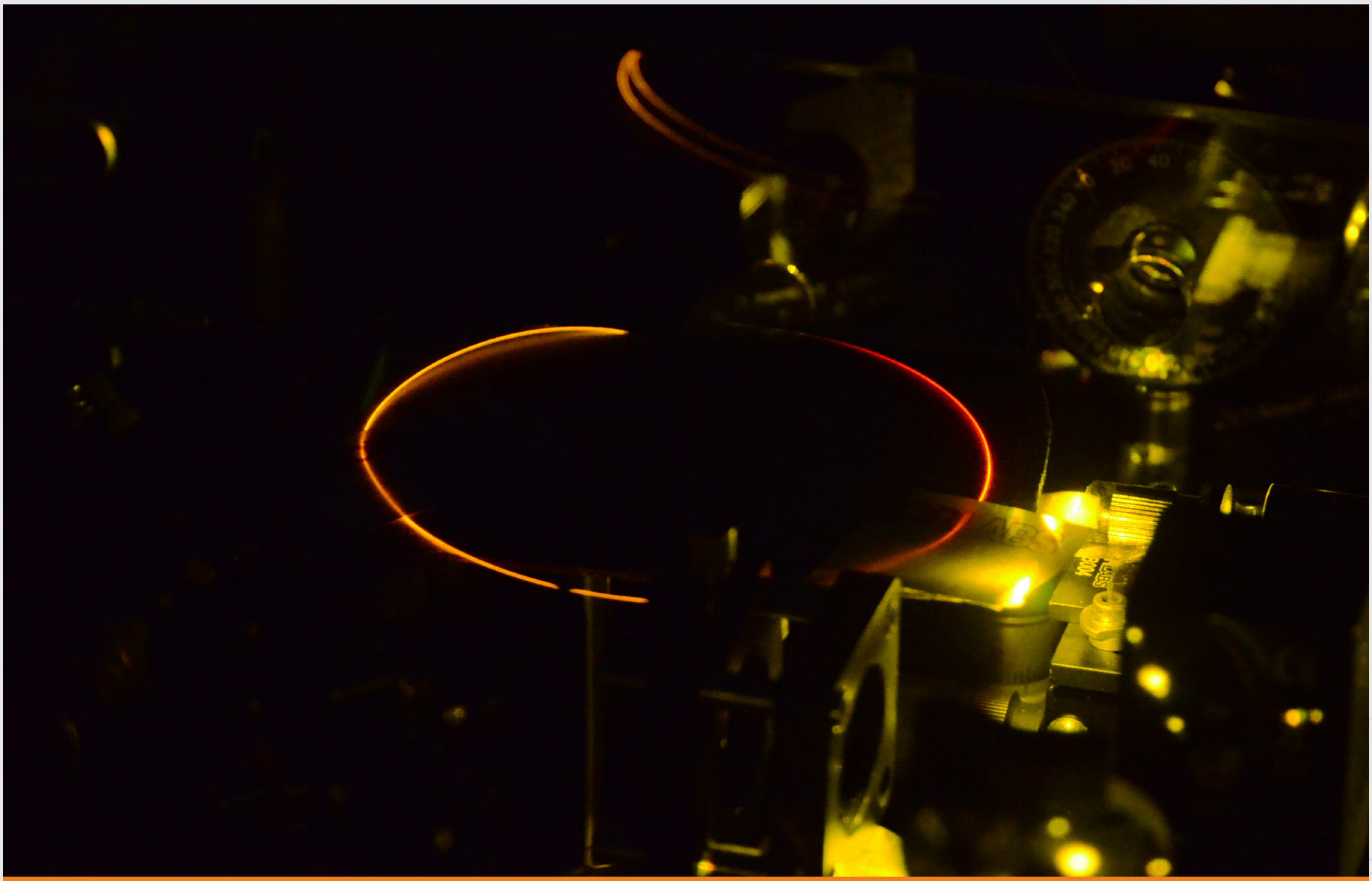


OPERATIONS:
ASTRONOMY

60

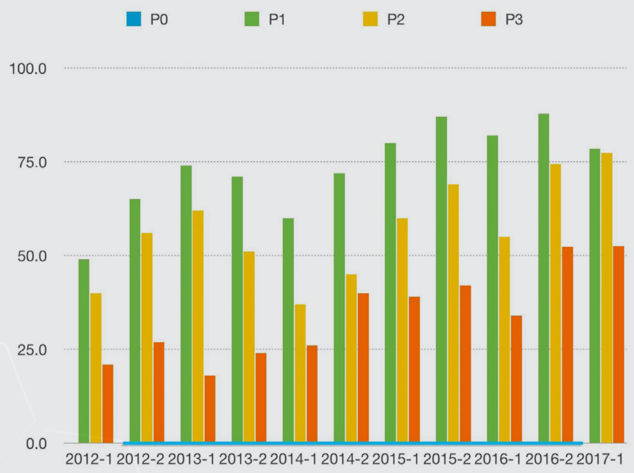


The 2017 semester-year was a record-breaking one: we had our best weather since the start of science operations in 2011, the most Blocks observed, the highest number of publications to date (49), and the best programme completion statistics. Furthermore, SALT was one of the first telescopes in the world to obtain a spectrum of GW170817, the LIGO gravitational wave event that marked the birth of multi-messenger astronomy. As a result, our data have featured in several high-impact publications describing this unprecedented astronomical event. Unfortunately, a few significant technical issues cost us also a record amount of observing time this year, particularly when a combination of operational changes degraded the telescope's delivered image quality. The latter prevented us from matching the best external seeing conditions for several months, negatively impacting high-priority programmes that had tight observing constraints. The painful lessons teach us the most! Further afield, over 50 participants from all of the SALT partner institutions attended an excellent three-day SALT science workshop that immediately followed the June SALT Board meeting in Kazimierz Dolny, Poland. This was the second meeting of its kind, following on from the 2015 SALT science conference held in Stellenbosch, South Africa. During 2017 we also completed the SALT Strategic Plan, which includes recommendations to build two new instruments for SALT. The plan was approved by the SALT Board during their November meeting in Cape Town.

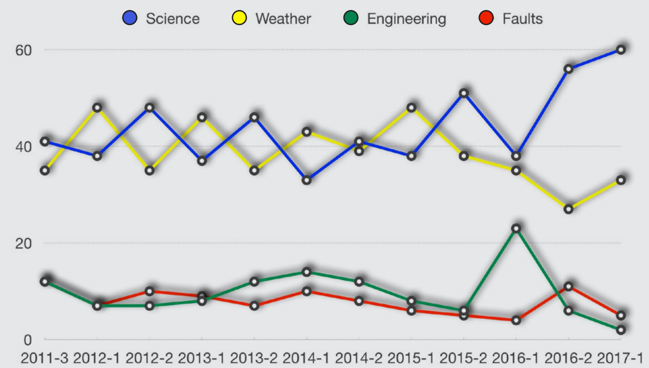
Semester statistics

Semester 2016-2 (November 2016 to April 2017) broke several records: P1 and P2 completeness fractions were 88% and 74%, respectively (see the figure below) and 1294 Blocks were observed. Of all programmes, 38% were fully completed. These numbers are even more impressive considering that SALT lost ten full nights to a serious tracker failure in March, our longest-ever run of technical downtime.

Semester 2017-1 (May to October 2017) was peculiar. For the second semester in a row the weather was unusually good, with a mere 33% of time being lost to weather, compared to the winter average of 45%. This resulted in 59% of time being available for science, well above the specification, and the highest value ever (for summer or winter) with nearly 300 additional hours of observing time. Hence the Block observing record was broken by a large margin, with nearly 1900 Blocks observed (about 600 Blocks more than in 2016-2). This essentially wiped out the accessible queue by early August, so Priority 4 (P4) time was used extensively, taking up about a third of the total observing time (compared to the typical 10–15%). A 3-week absence of RSS due to a cryostat problem in September/October, along with image quality problems, made it difficult to complete the more demanding science programmes, particularly those that were only available during the latter half of the semester. As a result, the P1 completeness fraction was only 79%, lower than in previous semesters. Overall, however, 2017-1 was extremely good, with 94%, 78% and 53% of P0, P2 and P3 time completed, respectively – either beating or matching previous records. Taking into account the fact that P3 time is over-filled by a factor of three, 96% of all budgeted charged on-sky time was completed.



Completeness (%) per priority



SALT time usage per semester

User support

The HRS pipeline came online in January 2017. It automatically extracts and wavelength-calibrates data for three of the instrument's four modes (LR, MR and HR) as part of the daily pipeline-reduction and data-distribution. This has increased the number of HRS proposals being submitted and facilitated the publication of results obtained from HRS data. The specialised high-stability mode of HRS is not included in the general pipeline; this more demanding application will be addressed in 2018. The SALT Science Database (SDB), which is at the heart of the telescope, underwent a significant upgrade to increase flexibility in handling proposals, in preparation for having to respond rapidly to incoming alerts.

SALT strategic plan

A new SALT science strategic plan* was finalised at the November 2017 SALT Board meeting. The strategy involves new investments, while at the same time capitalising on SALT's existing strengths and future collaborations, with, e.g., MeerKAT/SKA and LSST. The plan specifies ambitious goals for transforming the telescope into a world-leader in carefully selected research domains. The three science focus areas that will drive future development and decisions are:

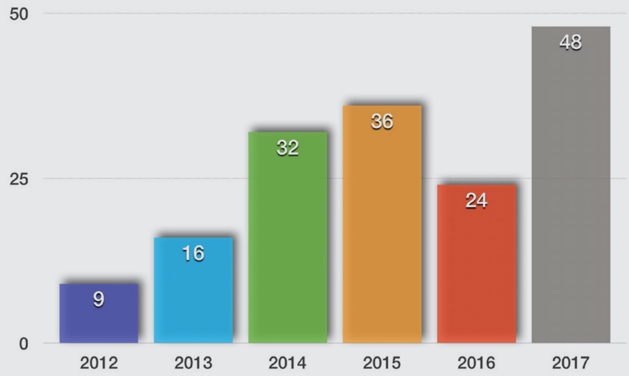
- Understanding fundamental physics and the nature of the Universe: Transient and time-domain astrophysics;
- Tracking the flow of matter from stars and galaxies to us: baryon cycle, galaxy evolution, and the low-surface-brightness Universe;
- Finding life in the Universe: Exoplanets and their characteristics.

Two new instruments are recommended to serve those drivers. The first is a 1.5-generation high-efficiency, single object, low-resolution spectrograph, the working title for which is "MaxE" (for maximum efficiency). This is to be developed as quickly as possible to serve transient science needs, particularly with MeerKAT (and later LSST and SKA) on the way. The other is a true 2nd-generation instrument: a large-format, deployable IFU to exploit the dark Sutherland sky for studying diffuse extragalactic objects in the nearby Universe. Focused effort will also be put into the existing HRS instrument's high-stability mode, to equip it for exoplanet studies in the short term. In addition, a feasibility study is to be undertaken to explore a way to revolutionise how SALT observes in the future. These science fields are tightly woven into an aggressive plan to grow local skills and capacity in SAAO-based astronomical instrumentation development, in part by working closely with instrumentation specialists within the SALT Partnership. The plan is designed to serve both the SALT Foundation and the knowledge and technology economies of South Africa.

Publication statistics

After a low publication count in 2016, the number of refereed SALT papers reached 49 in 2017, comfortably exceeding the 40 mark that puts SALT on track with international trends. The 48 science publications are equally divided between extragalactic (18) and Galactic/stellar (21) topics; five further papers are based on supernovae observations, and four papers include the SALT spectrum of the first multi-messenger event, GW170817. An additional paper reports on the HRS instrument and does not refer to a science programme. Results from 74 SALT observing programmes are presented in these papers. RSS observations contribute the majority of the data (85%), though HRS is beginning to feature (with seven papers this year), influenced by the release of the HRS data pipeline.

205 refereed SALT papers have been published in total, comprising 183 based on SALT data, 10 presenting general science cases using SALT and 12 involving instrumentation. Of the most cited SALT publications in January 2018, the combined multi-messenger astronomy paper on GW170817 by Abbott et al., published a mere three months ago, is already ranked third.



Refereed papers based on SALT science data, from 2012 onwards.

Personnel

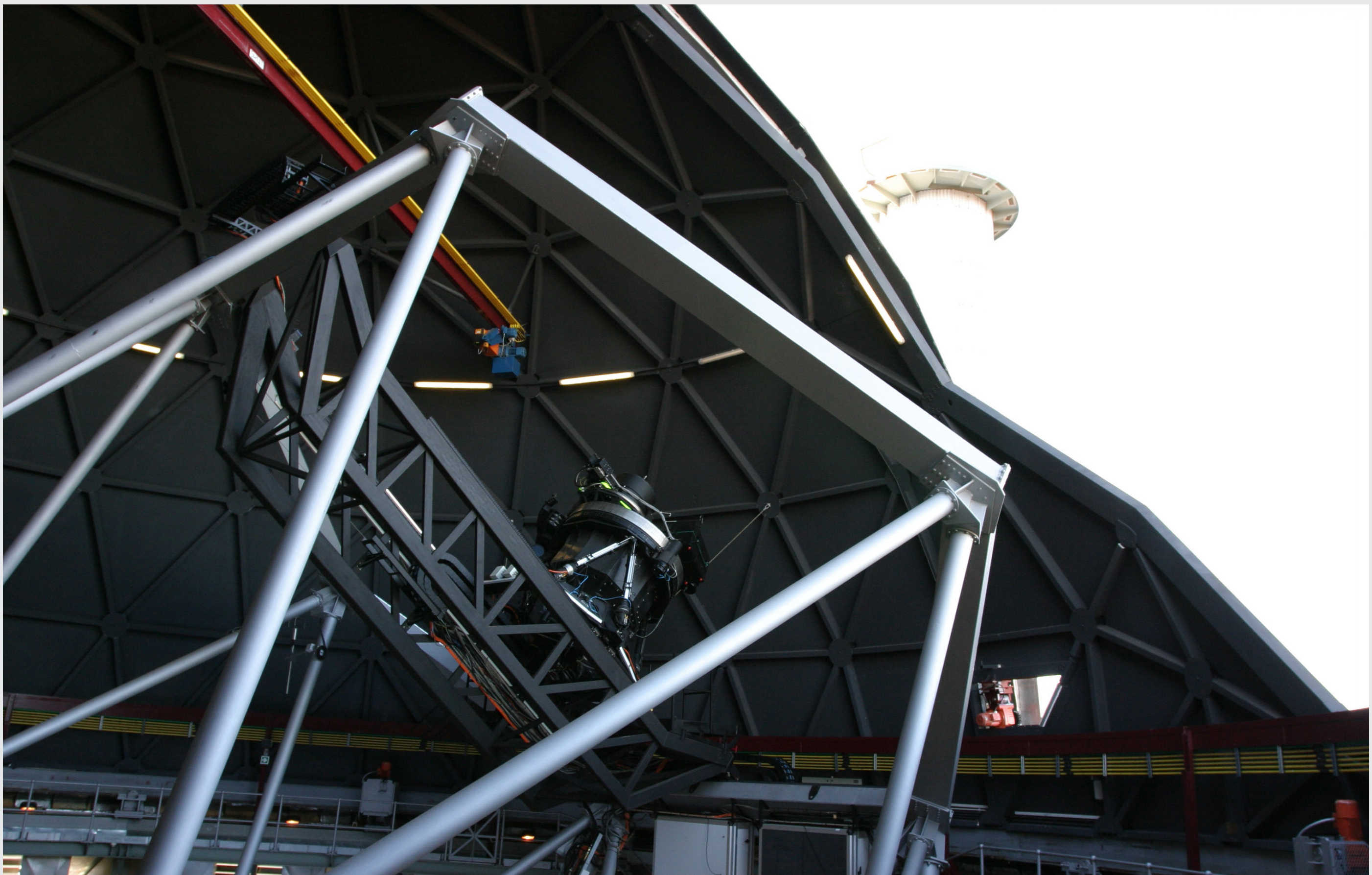
At the end of 2017, Dr. Petri Väisänen, the Head of SALT Astronomy Operations, became Professor Petri Väisänen, the new Director of the SAAO. In his place we welcome our longest-serving SALT Astronomer, Dr. Encarni Romero Colmenero. The vacant SALT Astronomer position that resulted has been advertised and is expected to be filled during 2018.

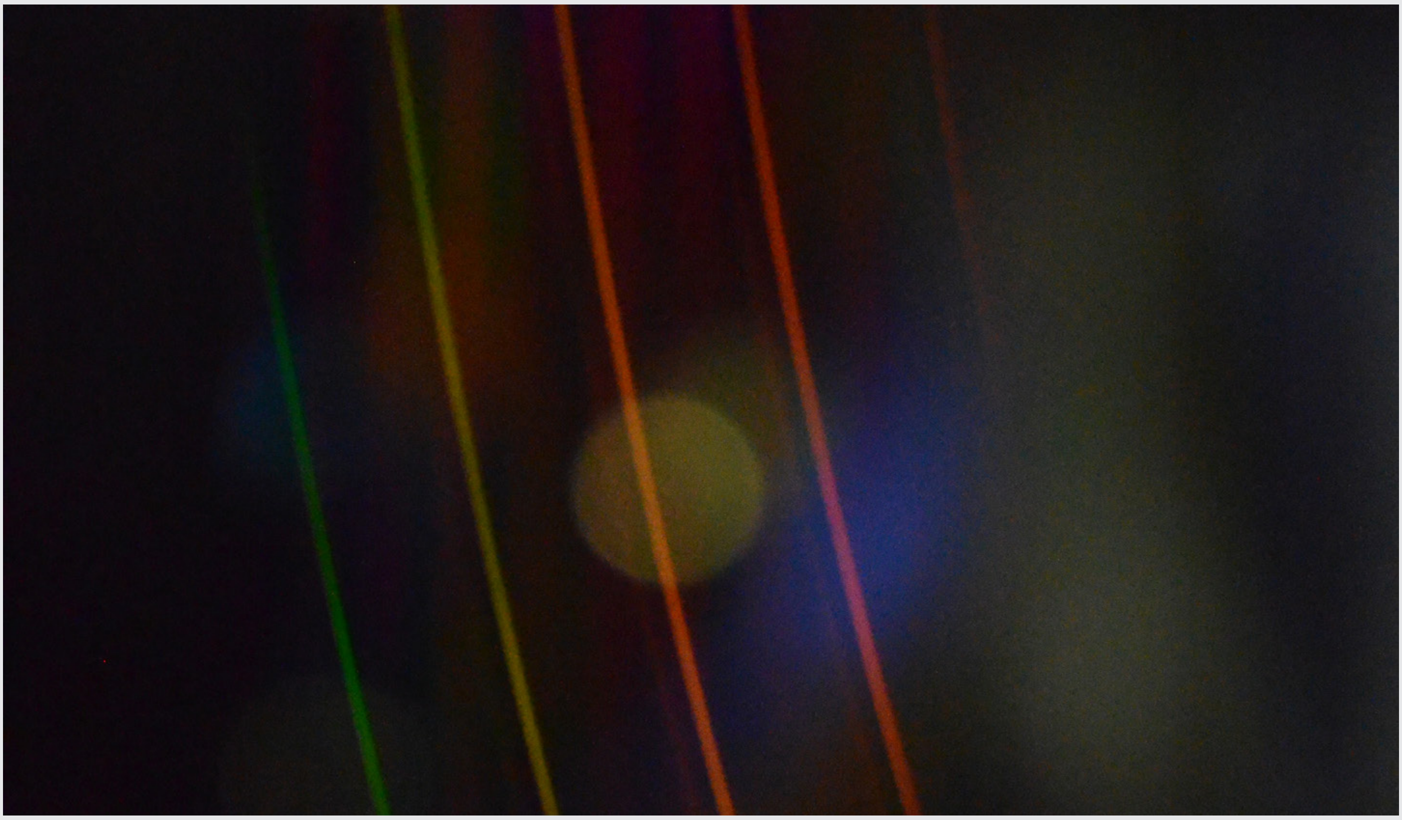
Nhlavutelo Macebele originally joined the Astro Ops team as a Department of Science and Technology intern allocated to the SAAO for a year. In September, after a highly productive term, he was hired as a software developer. Nhlavu's main responsibilities will be to work on SALT data-quality monitoring and the science database, as well as to develop a new SALT data archive.

* www.salt.ac.za/news/salt-strategic-plan-2017

OPERATIONS:
TECHNICAL

63





The SALT Array Management System (SAMS) now regularly maintains the primary mirror alignment for periods lasting up to a week, which is the period between mirror swapping, without intervention.

A major achievement during the year was to design and commission a system to extend operations to a lower dew-point delta of 1.6°C versus the previous 2.5°C. The international Review Panel proposed, after their October 2016 visit, that such an improvement be made. It is expected to increase observing time quite considerably with the further advantage of needing only a very small investment.

Another important achievement was the completion of a software project during which many outstanding software "tickets" were closed and other improvements done that are not possible under the day-to-day pressure of supporting telescope operations and projects. As a consequence, the shutdown planned for August 2017 was postponed to March 2018 to deploy key manpower to this project. The new guider for RSS was also put on hold during this period.

A successful short shutdown was completed in March 2017 during which maintenance was done to the pier, cooling of electronic systems (to prolong the life of the Segment Positioning System) and optical fibre installations.

A system engineering course was presented to the astronomers and senior technical personnel of SAAO. The course leader, Dr. Hermine Schnetler, is Head of Systems Engineering at the UK Astronomy Technology Centre based at the Royal Observatory in Edinburgh. System engineering is the process used to design and develop systems/products from a user requirement right through to operations concepts and maintenance. It will be applied during all future product development projects.

The slitmask laser cutter was successfully upgraded.

The SALT building exterior was painted. The dome was sealed to prevent rain entering the telescope.

A project is well underway to prepare the telescope and its sub-systems to receive the new near-infrared spectrograph during the second quarter of 2019. This project is done in close cooperation with the University of Wisconsin, the developer of the instrument.

An unfortunate setback was when RSS's cryostat failed on 16 September 2017. Despite various attempts, it could not be repaired on site and it had to be taken down and brought to Cape Town. It was repaired and the instrument declared operational on 12 October; in the meantime SALTICAM and HRS could still be used.

Personnel

The SALT Board approved four new positions for the Technical Operations team and recruitment is ongoing. One position in Cape Town has been filled but the three positions in Sutherland are proving to be a challenge to fill.

Healt and Safety

No on-duty safety incidents happened this year. A second successful fire evacuation drill, for the day crew, was conducted on May 15.

OPERATIONS:
INSTRUMENT NEWS

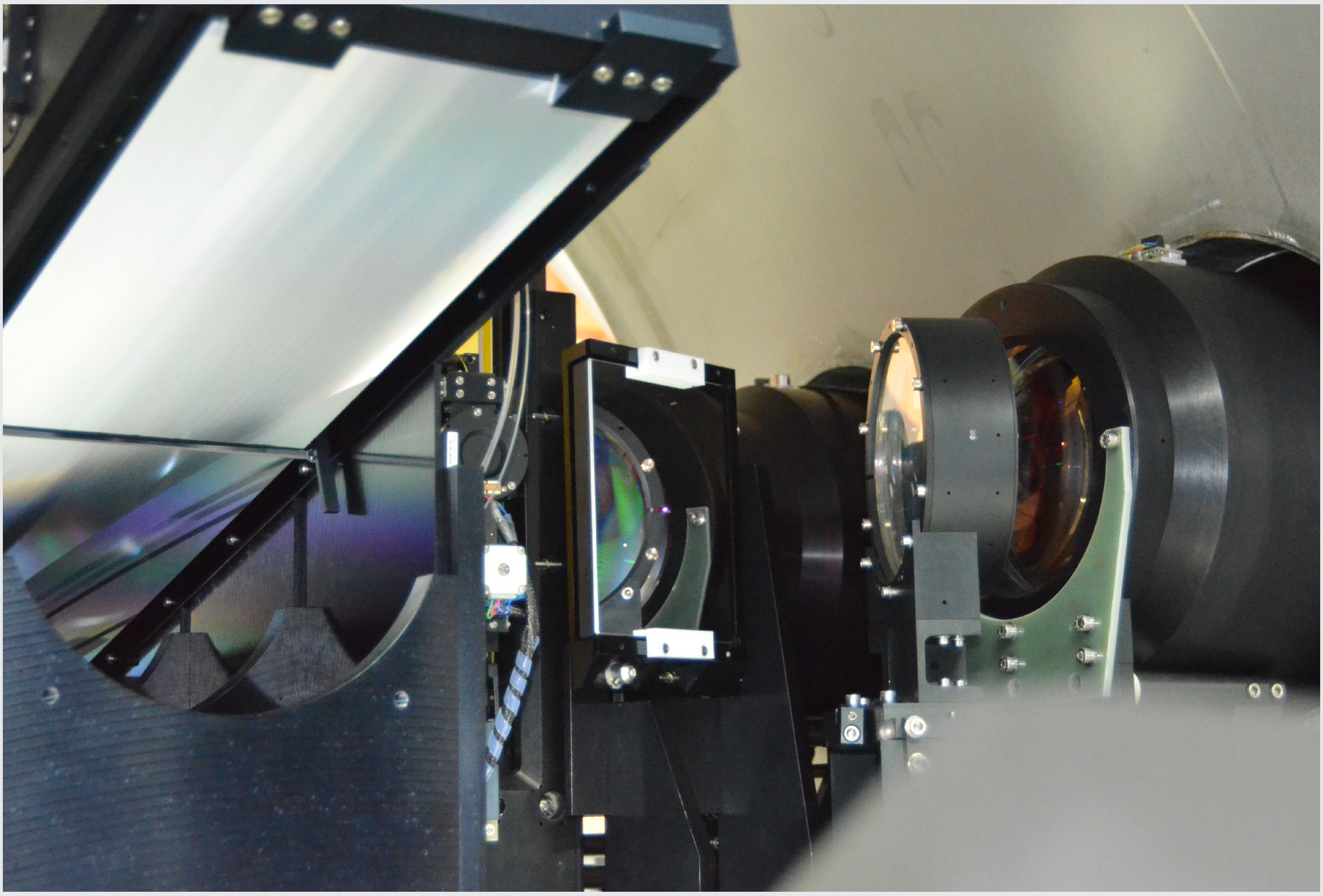
65

SALT INSTRUMENTATION UPDATES

Linear and circular spectropolarimetric modes on RSS have been commissioned and are now in regular operation with pipeline reductions being available to users. Dual-etalon Fabry–Pérot observations became possible following the introduction of a polariser between the two etalons. This eliminated the problematic internal reflections, but at the cost of a 50% throughput loss. The controllers were also relocated to be closer to the etalons and the shorter cables appear to have resolved the etalon instability issues. As a result, dual-etalon Fabry–Pérot observations have now become routine. The development of a new 2-probe guider system for RSS, which will also provide closed-loop focus control for RSS, is progressing well and is due to be installed during a shut-down scheduled within the first half of 2018.

Following the release of two data reduction pipelines for the non-specialist modes of the HRS, our focus is now shifting to the instrument's far more demanding High-Stability (HS) mode. Valuable contacts were established at the 2017 conference on Extremely Precise Radial Velocities held in State College, Pennsylvania, in August. As a result, the HRS iodine cells have been sent to the National Institute of Standards and Technology in the US for high-resolution calibration, and we will be collaborating with PRV specialists to optimise the HRS for work in this field.

A significant operational change made during 2017 has increased the amount of observing time available to all the SALT instruments. The somewhat conservative humidity limits were relaxed as much as possible, while still ensuring that the internal conditions will not result in condensation forming anywhere within the dome. The dew-point delta limit – the difference between the internal temperature and the dew-point – has been reduced from 2.5°C to 1.6°C, and the internal temperatures are based on surface (rather than air) measurements, obtained with new and meticulously calibrated sensors. The amount of on-sky time that this will save has yet to be established, but of course every minute is precious.



A NEW NEAR-INFRARED SPECTROGRAPH

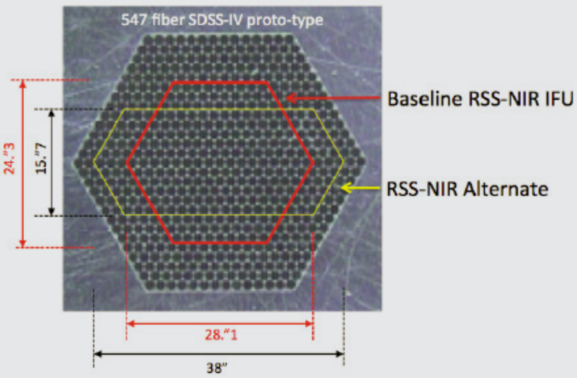
Development of the near-infrared arm (NIR) for the RSS is ongoing at the University of Wisconsin-Madison. Since the spectrograph will no longer be placed at prime focus, nor share a collimator with the visible arm of the RSS, it is essentially a separate instrument and hence it has been informally renamed "the NIR". It will require an optical fibre cable to convey the light from SALT's prime focus to the thermal enclosure in the spectrometer room beneath the telescope, as well as a separate collimator

The UW instrument team for NIR visiting SALT in June.

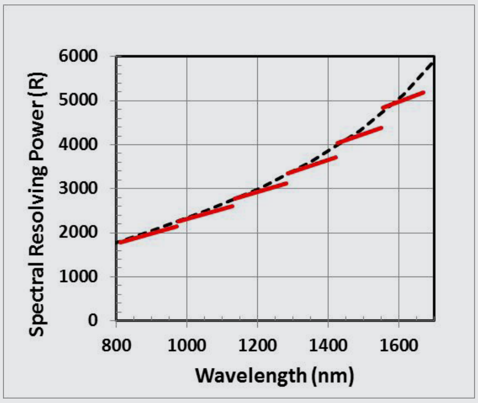
Washburn Astronomical Laboratories in the UW Astronomy Department is developing a NIR integral field spectrograph for SALT. This instrument will be the first to extend SALT's capabilities into the NIR, providing medium resolution spectroscopy at R = 2000–6000 over the wavelength range of 0.8 to 1.7 microns. The integral field unit (IFU) is a hexagonal bundle of 217 fibres, each of which subtends 1.3 arcsec on the sky, matched to the median site seeing. The IFU has dimensions of 24 x 28 arcsec on the sky, making it ideal for sampling nearby galaxies at slightly higher spatial resolution than the SDSS-IV MaNGA survey. Two separate blocks of 15 sky fibres can be adjusted to distances ranging 54 to 165 arcsec from the object IFU with a gimbaled jaw that maintains telecentricity and common field angles for the object and sky bundles. Sky fibres will be interleaved with object fibres along the 8-arcmin long spectrograph slit. This spectrograph was formerly known as RSS-NIR, which was designed to be mounted at prime focus and coupled to the existing ambient temperature spectrograph (RSS-VIS) through a dichroic beamsplitter. It was reconfigured into a fibre-fed bench spectrograph to stabilise the pupil illumination in the spectrograph by taking advantage of the azimuthal scrambling properties of fibres, to improve the instrumental thermal background with a separate cooled collimator, and to simplify telescope operations at prime focus. Flat-fielding and sky-subtraction of data obtained with the existing slit spectrograph has been challenging due to SALT's changing pupil as the instrument payload tracks across the primary mirror during observations. Simulations show that fibre scrambling of the pupil will improve the achievable sky-subtraction residuals of this NIR spectrograph by 1–2 orders of magnitude.

Core members of the UW-based NIR instrument team spent a week in South Africa in late June to work with the SALT Operations team, discussing interfaces and starting to define the various adaptations that need to be made to allow the telescope to accommodate the NIR. A local team is now working closely with UW to ensure that the necessary changes are made prior to the delivery of the instrument, and to facilitate comprehensive training and a smooth integration and hand-over process.

Current instrument status: the new collimator lenses are being fabricated, the cooled enclosure is being tested in the lab, and fabrication techniques for the 40-meter long fibre cable are being prototyped. Instrument delivery to SALT is expected in mid-2019.



IFU geometry. The background image is the face of a 547 fibre IFU built by Matt Bershady (UW-Madison) and collaborators for SDSS. The red and yellow hexagonal outlines show two options for the geometry of the RSS-NIR IFU consisting of 217 fibres. Its construction will use successful techniques proven on the SDSS-IV MaNGA IFUs and the larger prototype IFU pictured here.



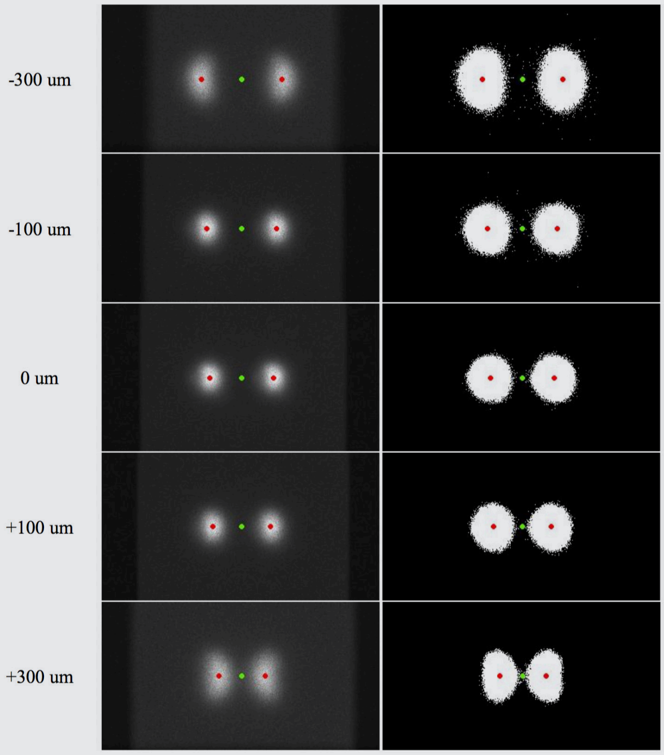
Spectral resolution with the initial 950 l/mm grating. The short red lines represent the free spectral range of single grating settings. The articulated grating-camera system will provide continuous angle settings in 0.5-degree increments, similar to RSS-VIS. Future gratings can fill in resolution-wavelength space.

A NEW PRIME FOCUS GUIDANCE SYSTEM

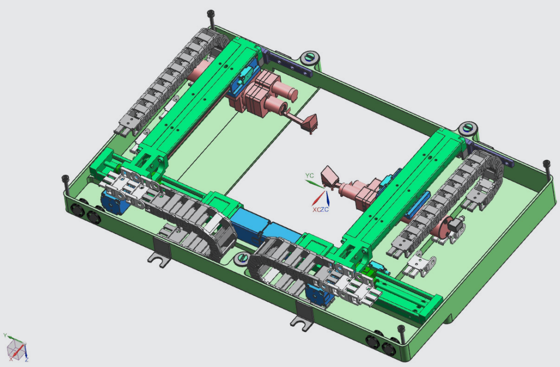
Over the last two years, a new SALT prime focus guidance system has been designed in the form of a compact, modular and removable system with high optical efficiency. The guider and its control electronics were designed from the ground up with reliability and maintainability in mind and can be removed from the telescope for maintenance without the need to remove the RSS. Two, identical, guide star pick-off systems are positioned independently allowing not only translation guidance, but also field de-rotation correction that is crucial during long-exposure multi-object-spectroscopy (MOS) observations. Optional beam-splitting of the guide star images allows closed-loop focus feedback to actively stabilise the focal plane.

The optical layout of each pick-off system is shown in the ray-trace diagrams below where a 'pyramid wavefront sensor' (PWFS) prism splits the image of the guide star into two spots on the detector. The effect of defocusing the telescope with the tracker on these doubled images is shown on the right. The amount of defocus is measurable as a change in separation between the spots, independently from any common motion that may be induced by atmospheric seeing or translational tracking errors.

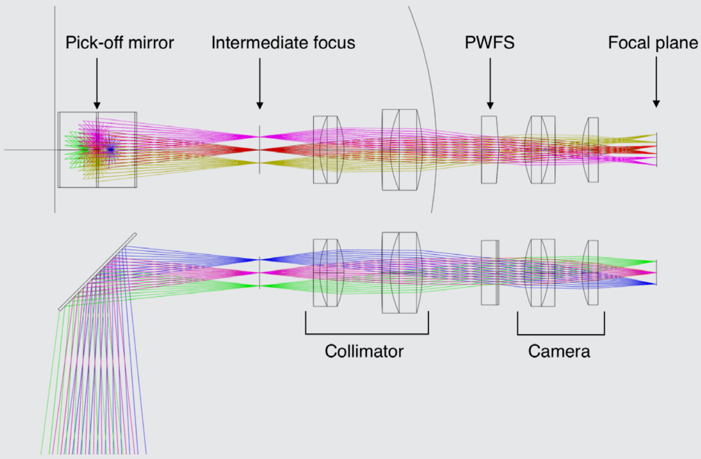
Compared to the original fibre-fed system, direct re-imaging of the guide stars onto integral detectors improves optical efficiency by a factor of eight, allowing guidance on much fainter objects. The accurate linear motion design reduces guide star acquisition times and allows for the precise positioning of science targets while closed-loop guidance is active.



Effect of changing telescope focus (y-axis) on the doubled images created by the PWFS. The left column shows the actual images, while the regions-of-interest used for calculating the centroids are indicated on the right.



A schematic of the pick-off probe positioning system that mounts to the RSS instrument.



The optical layout of each pick-off system.

SALT AS AN INSTRUMENT TESTER: THE EXPERIMENTAL LASER FREQUENCY COMB

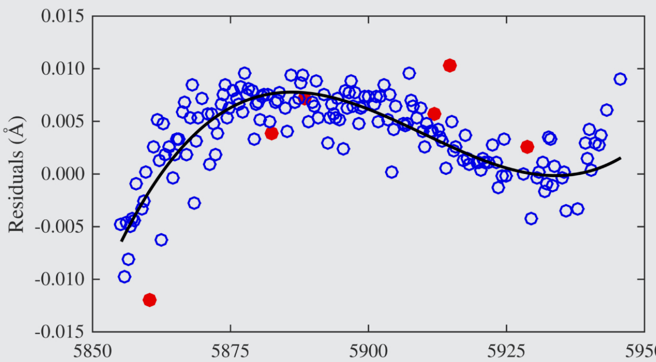
The good news is that SALT has been highly successful in testing a newly-developed instrument, in this case a laser frequency comb called CRISP (Calibration Ruler for Increased Spectrograph Precision). Regrettably for the SALT community, the comb was only on short-term loan before being returned to the builders, albeit with a trove of information garnered during the tests and evolving plans for an upgraded version.

High-accuracy wavelength calibration is becoming more important for high-resolution spectroscopy. The ever-increasing collecting area of telescopes as well as the increasing sensitivity of astronomical instruments has enabled the detection of fainter signals and signals with small-scale variations from astronomical objects. Thus, it has become more critical than ever to be able to precisely pinpoint the wavelengths of spectral features. The most accurate calibration source is currently provided by laser frequency combs. Their intrinsic accuracy is better than 10^{-15}, which is several orders of magnitude better than the precision achievable by a high-resolution spectrograph. Thus, combining the two allows absolute calibration of high-resolution spectra.

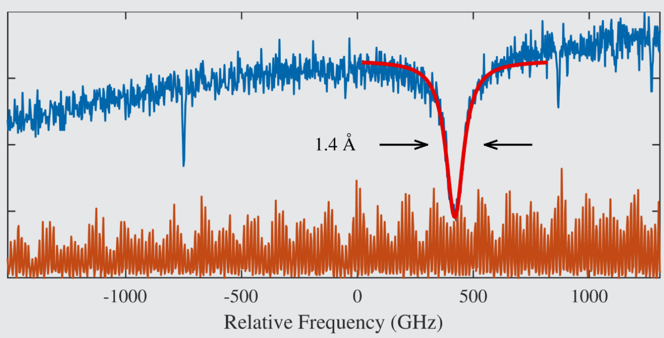
Heriot-Watt University in Edinburgh, Scotland, is one of the world leaders in ultra-fast optics, and they have mastered the art of building stable, but transportable, laser frequency combs. An extremely fruitful collaboration between Heriot-Watt's Richard McCracken and Derryck Reid and a SALT team consisting of Rudi Kuhn, Éric Depgane, Nic Erasmus and Lisa Crause began in 2016. The main goal was to test, for the first time, an experimental laser frequency comb on a high-resolution spectrograph, attached to a large telescope. In other words, to take a precision-calibration device out of its native laboratory environment and subject it to the operational realities of a working astronomical observatory. This amounted to a fascinating and highly-instructive culture-clash for observational astronomers and laser physicists alike!

In April 2016, the combined team installed the comb, which spanned the full 555–890 nm range of the red channel of SALT/HRS. They were soon able to combine real observations of astronomical targets with the remarkably accurate wavelength-calibrated light from the laser frequency comb: using a novel co-coupling method to inject comb light into the spectrograph, they were able to simultaneously observe on-sky and record both the routinely-used Th-Ar lamp and the astrocomb channels. This revealed that the increased number of calibration lines per diffraction order provided by the comb reduced the wavelength-solution fitting error by a factor of two compared with a Th-Ar lamp. This leads to a corresponding improvement in the rms radial velocity measurement error from 20 m/s to 10 m/s. The team also observed the spectrophotometric standard star LTT7379 and determined the FWHM of the Hα line to be 1.40 Å, in full agreement with existing measurements (1.33 – 1.40 ± 0.1)Å, while the Th-Ar calibration gives only 1.19 Å due to the lack of emission lines in that order.

Several other tests were performed over a period of three months to monitor the stability of the comb itself. This provided valuable information to feed into the development of future astrocombs, particularly in terms of stability and environmental considerations. Although these tests only involved the red channel of the HRS, it is expected that the next generation of astrocombs will offer significantly wider wavelength coverage for optical spectrographs. In the meantime, Richard McCracken and his co-authors have demonstrated that a broadband astrocomb that can be operated by non-specialists is not only technically possible, but already a reality.



Wavelength solution residuals for a single order of the red channel of HRS. Residuals for a fit to six Th-Ar emission lines are shown in red, while those for the astrocomb are shown in blue.

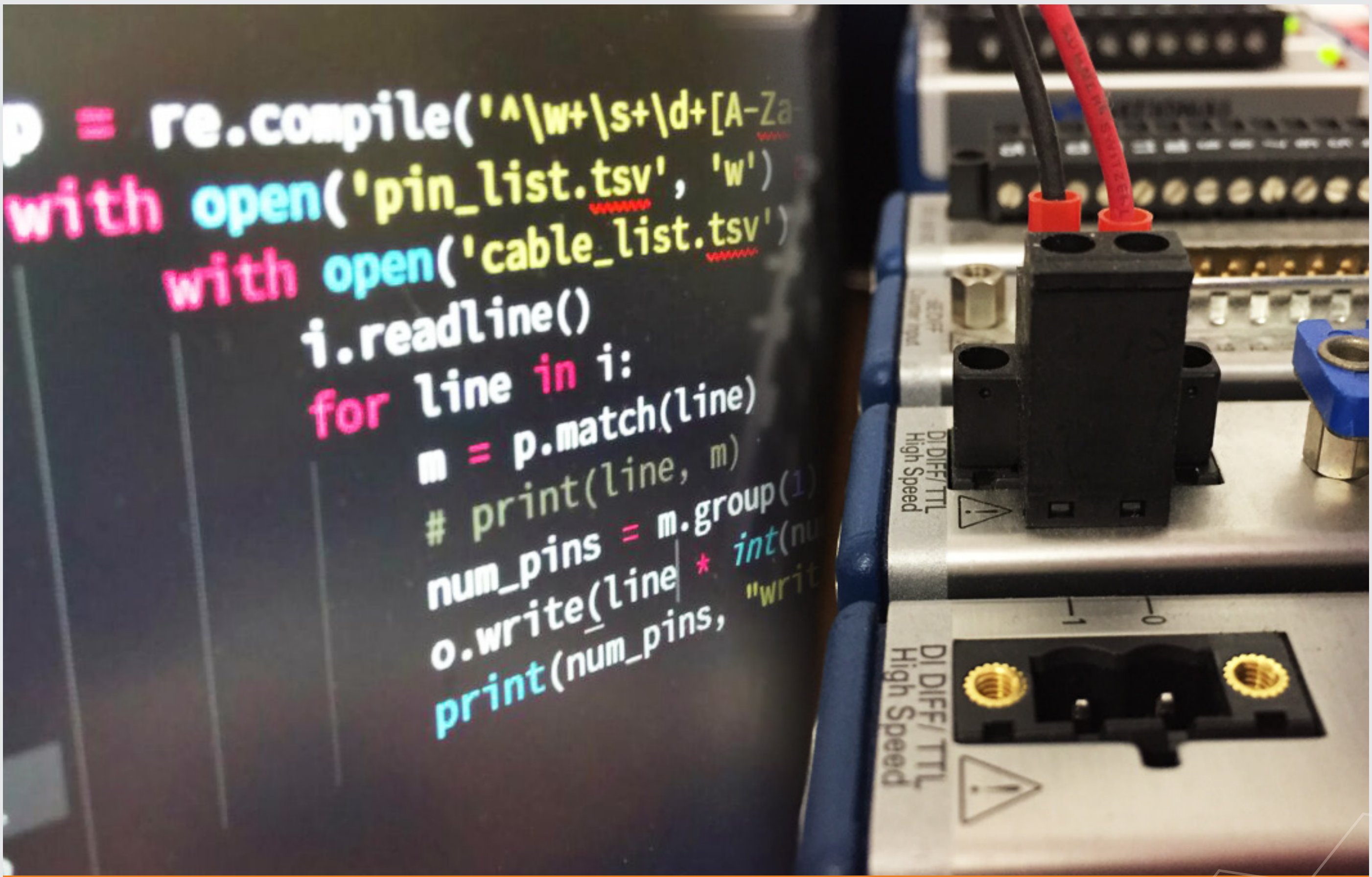


Comb with mode spacing of 15 GHz (bottom) and a spectrum of the spectrophotometric standard star LTT7379 (top), showing the Hα absorption feature and fit (red) inferred from the comb calibration.

McCracken, R.A., et al., 2017/03, Optics Express 25, 6450: Wavelength calibration of a high-resolution spectrograph with a partially stabilized 15-GHz astrocomb from 550 to 890 nm

OPERATIONS:
SOFTWARE UPDATES

70



THE ONE AND A HALF DECADE LEAP IN THE RSS CONTROL SYSTEM

The RSS optics maintenance in August 2017 provided the ideal opportunity to upgrade the RSS control computer. While the team got to work on mechanical maintenance, the software group set about upgrading the entire control system that was still running LabView 6.1 (originally released in 2002) on the Windows XP computer delivered by Wisconsin. The antiquated computer and software raised concerns about replacing items should a failure occur. In particular some of the driver files specific to XP and LabView 6.1 were no longer available. This long-overdue upgrade represented a one and a half decade leap in software and computer hardware advancements. RSS is a delicate instrument with precision optics, and changing so many aspects of the control computer threatened to cause difficulties. Hence this upgrade was delayed until the spectrograph was on the ground where it could be monitored closely during testing. A new PC running windows 7 was installed with LabVIEW 2015.1. The PXI rack containing the motion control and IO cards required a firmware update. The PCON software was successfully upgraded to run on the new LabVIEW platform, and required significant changes to communicate to the new version of MAX, LabVIEWs motion control and acquisition interface software. The new setup runs significantly faster than the previous version, which led to a few timing bugs, but otherwise the upgrade went smoothly. As a result, the RSS now has a modern control computer and all components are easily replaceable should anything fail.

THE NEW IMPROVED SOFTWARE CHANGE MANAGEMENT SYSTEM

During the initial days of the SALT project, software development followed an approach where speedy development and deployment were crucial. As the control software is now complete and working, the team can focus on improving efficiency. This year, a software change management process has been implemented to help with this. It concentrates on improving stakeholder communication and feedback, two issues that were causing frustrations for all concerned. New changes are now requested through a ticket system. A champion is assigned to each sub-system and is responsible for determining if the proposed changes are necessary. All changes are then evaluated and confirmed by the champion before the ticket is closed. The new system has been in use since June 2017 and has already improved the quality of the software being deployed at SALT.

INTERNAL WEB INTERFACES

Updates have continued to be made to the internal web-based monitoring tools used by the SALT Operations team. The readability of the data displayed on WebELS has been improved, reducing the time taken to successfully analyse and troubleshoot problems. This tool allows time-series data from some of the fifteen thousand inputs and sensors on the telescope to be displayed and correlated. The Science Database upgrade later in the year was an opportunity to improve the WebSAMMI site used by the astronomers to record the nightly logs. The generation of the summaries of the observed blocks was incorporated into the tool, streamlining the creation of the nightly logs that are sent out to PIs the next day. After encountering difficulties in coordinating the compilation of the daily SALT software log between Sutherland and Cape Town, and struggling to identify the software configuration of the telescope at a point in time, a new, automated system to record and consolidate the changes made to the telescope on a day-to-day basis has been developed. This has resulted in a reduction of administration overhead, more complete and timeous reporting of changes, and a daily report that is consistently formatted and contains easily searchable metadata.

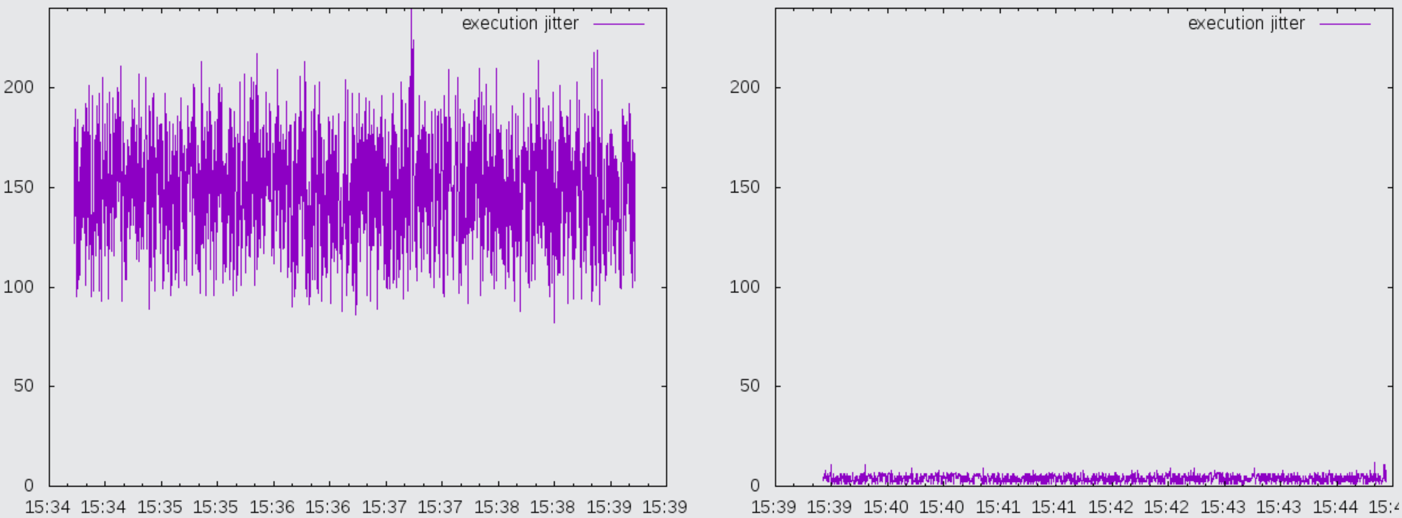
NATS COMMUNICATIONS IMPROVEMENTS

The control system for the SALT telescope is assembled from various independent components. For the telescope to work as a whole, these individual pieces need to be able to communicate. The design choice of programming language for the control system was LabVIEW, making its native DataSocket communications protocol a natural choice.

Unfortunately, DataSocket presented some stability and scalability issues that only became evident after extensive use. The proprietary nature of the protocol barred us from sufficiently troubleshooting these problems, and also prevented us from fixing any of the root causes. To circumvent these difficulties, we developed an in-house solution that makes use of the Web Distributed Authoring and Versioning (WebDAV) HTTP protocol extension. Full control over the software allows tracing and rectifying any defects that may crop up. However, a major disadvantage of HTTP is that one needs to continuously poll the server to discover new messages. This polling introduces overhead as well as message time delays.

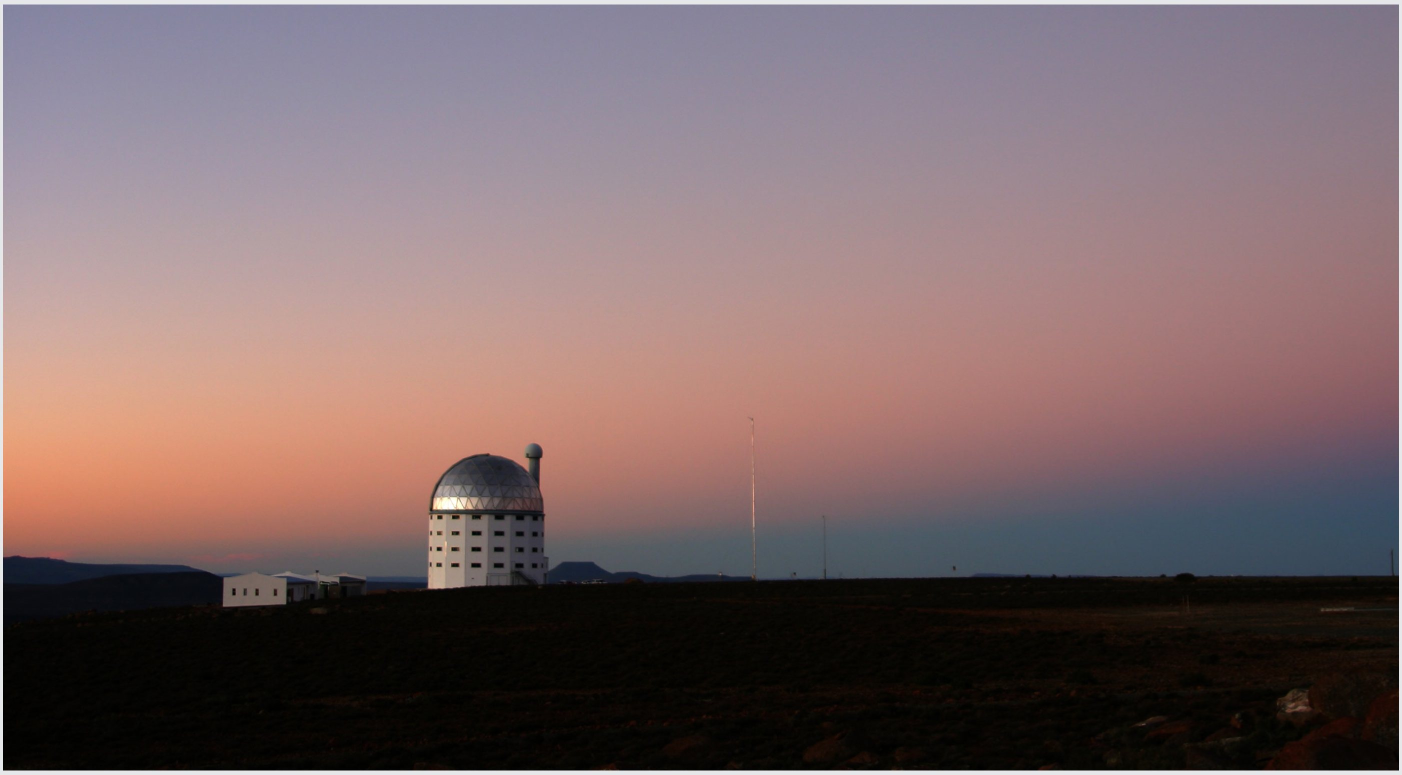
After much research and exploring options such as Data Distribution Service (DDS) and ZeroMQ (ZMQ), we selected an open source messaging system called NATS for communications. Its core design principles are performance, scalability and ease of use. One point that illustrates these values is that NATS is equipped with a simple, text-based protocol. This allows one to easily implement a client in the programming language of choice; we were thus able to implement a client in LabVIEW with little difficulty. NATS also supports various messaging models. One of the models, called "Publish-Subscribe", provides a one-to-many communication mechanism. A publisher defines a subject that can be subscribed, then any message sent on that subject is delivered directly to all subscribers.

We ran various tests to discover the performance differences between the HTTP-based polling messaging system and the event-driven NATS messaging system. The figure below shows the results of such a test where we measured the time-of-flight, or latency, between a message being sent and when it was received by the subscriber.



Time-of-flight measurements using an HTTP-based protocol (left) and using NATS (right).

OPERATIONS: SOFTWARE UPDATES



THE SALT PROPOSAL SUBMISSION PROCESS UPGRADE

When the software for SALT was planned and realised over 10 years ago, the envisaged use case was that of a single semester proposal with a small number of targets. In reality however, most proposals routinely span multiple semesters and may have dozens or even hundreds of targets, some of which are non-sidereal. Looking forward, SALT will particularly need to respond to the needs of the next generation of transient science: in light of the upcoming era of LSST, SKA and time-domain astronomy, there is a clear need for automated, rapid submission of a large number of targets.

For these reasons, a major review and upgrade of all the software involved in the proposal process was undertaken. At the heart of this upgrade were major changes to the design of the SALT Science database (SDB), a MySQL database containing all of the proposal information: whereas previously most of the data was linked to a single submission of a proposal and was updated on every resubmission, information is now being re-used more efficiently. In addition to catering for proposals with multiple semesters and/or many targets, the database upgrade also paves the way for allowing the submission of single observation blocks, with a view to fully automate the process in the near future.

This database paradigm shift had, however, repercussions for almost all of SALT's software, and a substantial challenge of the upgrade was to accommodate legacy proposals. Despite over 30 software systems being affected by the changes, a seamless transition to the new database architecture was carried out on 5 October 2017, with zero downtime to operations.

There were a few minor teething problems with our Principal Investigator Proposal Tool (PIPT) for submitting proposals. These were quickly ironed out thanks to efforts of a small group of PIs using our system, who provided helpful feedback and suggestions. As a result, the PIPT is now able to handle proposal versions for multiple semesters at the same time. This upgrade of the PIPT also focused on improving navigation, e.g., by allowing one to sort observation blocks and targets by name or target coordinates. The whole submission process has become simpler and more streamlined for investigators.

Major upgrades were also required for the Web Manager, SALT's browser-based software for accessing proposals. In addition to the necessary changes under the bonnet, we decided to take full advantage of the new SDB design and create a completely new website for the time-allocation process. Work has started on this site and will be completed in early 2018. This new site will contain a page with proposal statistics, a page for each partner to allocate time to their proposals and a page for administration by the SALT Astronomers.

In summary, the SALT proposal process upgrade was a major and necessary undertaking, which went online without a hitch and has unlocked exciting new capabilities for SALT, especially for transient science.

OUTREACH & EDUCATION

OUTREACH & EDUCATION:

SCBP ACTIVITIES

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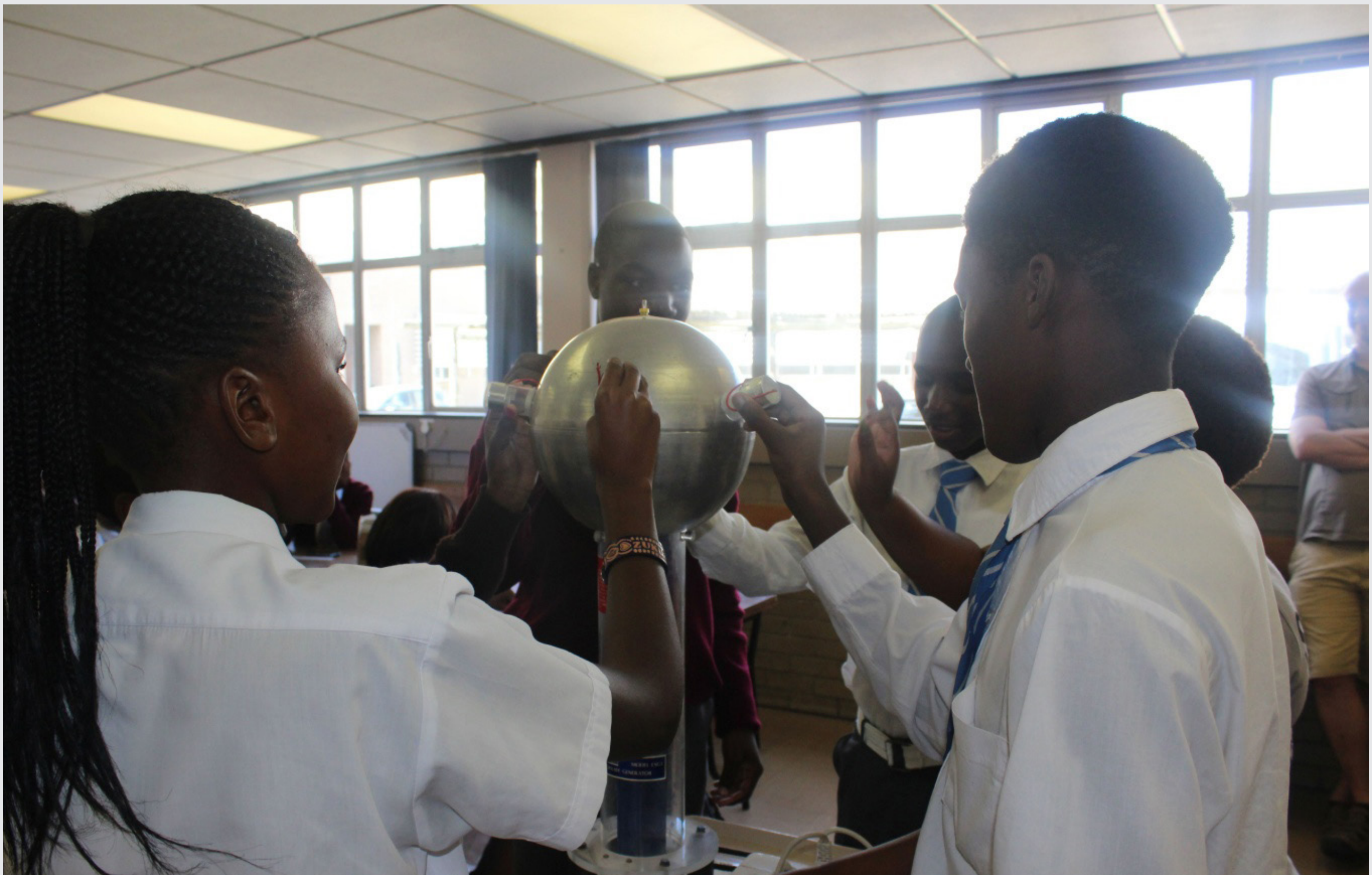


SALT COLLATERAL BENEFITS PROGRAMME ACTIVITIES

The SALT Collateral Benefits Programme (SCBP) was established during the construction of SALT and the objectives of this programme were clearly directed at the benefits derived by society from building this large telescope. Its focus points today are: education in mathematics, science, engineering and technology; science communication and awareness; socio-economic development, and public engagement. Today, the SCBP activities are run by the SAAO science engagement personnel.

The SCBP team has done magnificently in fulfilling its mandate in 2017 as 115,987 people were reached through the unit's programmes and activities. These activities include open nights, Sutherland and Cape Town site tours, astronomy based competitions, teacher workshops, learner enrichment programmes and public stargazing sessions. A total of 670 teachers were trained through teacher development and support programmes, 21,781 members of the general public visited our sites and 93,536 learners were engaged in our various learner-based programmes and workshops.

TEACHER TRAINING

SCBP is committed to contributing towards improvement and development of teacher quality and classroom practice. In an effort to empower teachers, and also in response to calls for assistance from the various provincial departments of education, we designed an intervention programme for the North West and Mpumalanga provinces. Week-long teacher training workshops were facilitated in collaboration with the Mondi Science Centre and Gert Sibande District. They focused on the theme 'Earth and Beyond'. Teachers were provided with relevant curriculum content and were exposed to creative pedagogical approaches to teaching the astronomy based theme. This included encouragement and support for naked-eye observations, use of astronomy software such as Stellarium and Celestia, hands-on activities, simulations and investigations. 442 teachers participated in these workshops. The unit also trained teachers in the rural towns of the North West province, done in collaboration with the North West Education Department; 170 teachers participated in these week-long trainings. Videos and documentaries based on SALT were shown and copies of a video from the American Museum of Natural History, which featured Dr. Thebe Medupe (who hails from the region), were distributed.

In collaboration with the University of Cape Town School of Education, the annual teacher training workshop was facilitated at SAAO for 15 pre-service teachers. The workshop focused on how to use astronomy as a context for teaching mathematics and science. This group of teachers was fortunate to have visited the observatory in Sutherland and had a memorable experience at SALT. They also received many resources for use in their classrooms to help with teaching mathematics and physical science.

LEARNERS ACTIVITIES

A total of 93,536 learners were reached through curricular, co-curricular and extra-curricular activities. These included an astronomy quiz, an astronomy essay competition, science clubs and job shadowing. Learners were also reached through participation in science festivals, exhibitions, public stargazing, learner workshops and school outreach activities.

Telescope Naming Competition

In a bid to publicise SAAO's new 1-m telescope at Sutherland and to find a name for it, a telescope naming competition was launched. This competition targeted learners from intermediate phase to high school (grade 4 – 12), resulting in 232 entries suggesting a name with a motivation. Choosing the winning name was a mammoth task for the judges. It was agreed unanimously that the winning name is Lesedi – a Sesotho/Setswana name meaning "Light". From now on the new 1-m telescope will be known as Lesedi! The name was suggested Sam Mpho Mthombeni, a grade 9 learner from the North West province.

Learner Workshops and Visits

The SCBP learner and school outreach programme remains popular with the schools. Our learner workshops attract learners to visit the Observatory both in Cape Town and at Sutherland. All our workshops are based on the natural science school curriculum and include hands-on activities which learners can take home. This has a ripple effect as it encourages learners to engage in conversations with each other and also with their family members. All our activities use simple, cheap and accessible materials. The Tuesdays and Wednesdays in 2017 were all fully booked.

Due to socio-economic challenges and distance, some schools are unable to visit the Observatory, and the SCBP staff strive to fulfil the learners and teacher wishes by visiting their schools. These school visits are linked to stargazing and the running of shows in an inflatable planetarium dome.

Astronomy Quiz

The annual Astronomy Quiz is very popular in both the Western and Northern Cape provinces. The use of the online version of the quiz is making it easier for the rural based learners and schools to participate. This year we introduced the quiz to new areas which previously have not participated, including towns such as Prieska, Potsmansburg and Upington. 841 grade 7 learners participated in the Astronomy Quiz. Teachers also look forward to participate in the quiz as it not only improves the confidence of the learners, their knowledge content and their interest in science but it also provides teachers with resources and exposure to modern discoveries and current updates in astronomy. Dr. Christian Hettlage, a SALT software developer, has been instrumental in helping the SCBP unit with the design and implementation of the Astronomy Quiz online.

Job Shadowing

We hosted four job shadowing sessions in 2017. These involved 23 learners as well as astronomers, software developers, information technology staff, engineers and education and outreach personnel from SAAO. Our job shadowing programme has been transformed from having a focus on astronomy to a more holistic programme that also highlights related careers that play a role in the field of astronomy. Job shadowing is a two-day intensive programme that exposes learners to experiences from observers and theorists. It also introduces them to the continuation from observation through data reduction and analysis to interpretation and publication.

The job shadowing programme has grown considerably and many students have shown interest in participating. Plans are being made to increase opportunities for learners to be exposed to careers in astronomy. Thanks to all astronomers, software developers and other staff, who have participated in the job shadowing programme, and particularly to Rudi Kuhn, Rosalind Skelton, Marissa Kotze and Carel Van Gend who have consistently availed themselves for this programme.

Science Clubs

The SCBP unit continues to encourage the establishment of science clubs across the country. Science clubs are vital in the conservation and further development of interest in science inspired by visits to an institution such as ours. Buzani Khumalo and Sivuyile Manxoyi have been involved in supporting the development of science clubs, with over 400 of them having been formed. SCBP has introduced new activities such as the Robotics and Globe project for clubs in Langa, Phillipi and Khayelitsha. This has been achieved through collaboration with SAASTA and UNISA. In collaboration with Ithemba Labs and SAEON, new science clubs were established in Phillipi and Langa.

ACTIVITIES FOR THE PUBLIC

Science Festivals, Career Expos and Exhibitions

In an effort to popularise astronomy and science in general, SCBP participates in national, provincial and regional science festivals. Thousands of learners and the general public are reached through participation in these festivals. Audiences from outside the Western and Northern Cape provinces also have the opportunity to personally interact with the Observatory staff via these festivals.

These events give the SCBP team an opportunity to disseminate information about SALT, SAAO, astronomy as a career and science. They also provide platforms to use astronomy to inspire interest in science among learners and the general public.

SALT remains our draw card and large source of inquiries from participants in these festivals. With the building of the radio telescope MeerKAT, SALT has attracted even more questions, mainly based on the difference between radio and optical telescopes and on their locations.

The SCBP team participated in SciFest, Science Expo, Uphongola Career Expo, Scitube, Paul Pietersburg Career Expo, Kirkwood Festival, Lusikisiki Career Expo, Oude Molen Career Exhibition, Gugulethu Career Expo and the Eiding Festival.

Open Nights

A total of 22 SAAO open nights were held with 1862 people attending these events in 2017. The open nights include a public lecture, a tour of the SAAO Museum and a stargazing session. Twenty-four different astronomers from SAAO, UCT, UWC and SARAO gave these lectures in 2017, with the audience ranging from 60 to 140 depending on the topic. The historical McClean Telescope remains the major open-night attraction. It has however proven difficult to maintain the telescope due to financial challenges. The open nights remain very popular and attract not only the local people but also tourists.

Cultural Astronomy Project

A new project funded by the Department of Science and Technology and based on cultural astronomy was initiated in 2017. The aim of this project is to promote cultural astronomy, to use cultural astronomy to advance astro-tourism and to promote storytelling as medium of science communication. Three events have been implemented so far. Firstly, an event dubbed 'Stars under Karoo Skies' was carried out in Sutherland. This was a combination of storytelling based on stars done by a well-known South African storyteller, Dr. Gcina Mhlophe, followed by naked-eye and telescope-based viewing of stars. Secondly, a storytelling programme based on stars was performed for young children and lastly, a science communication workshop took place in Cape Town which focused on using storytelling as a medium for communicating science.

We are currently working on producing a booklet with stories from different South African cultural groups about the stars and how these cultures used the stars for daily living. This will be accompanied by audio and audio-visual resource based on indigenous understanding of the stars.

SUTHERLAND ACTIVITIES

Visitor Centre

The Sutherland Tours are extremely popular and the number of visitors is constantly increasing. In 2017, 12,015 people visited Sutherland. Astronomical events seem to spur interest and encourage people to visit Sutherland. We have been advertising in various tourist magazines and sites, and SALT is one of the greatest attractions for people to visit the Northern Cape province. We are continuously promoting astro-tourism in Sutherland, and tourism continues to contribute to the socio-economic development in Sutherland by way of jobs for the youth of Sutherland and surrounding areas. Furthermore, training for new tour guides was provided in conjunction with the Centre for Astronomical Heritage.

In mid-2017, we commissioned an evaluation of our visitor centre. We are now in the process of improving and restructuring the centre and producing new exhibits. One of the changes will be to highlight discoveries and studies conducted on our telescopes, as well as featuring our astronomers to respond to questions from our visitors.

Community Development Centre

The community development centre continues to serve as a rallying point of development in the community of Sutherland. Workshops based on foetal alcoholic syndrome, internet-based banking, website designing and social media were provided for the community. Members of the community have free internet access through the centre. This allows access to job opportunities outside Sutherland, to promote their businesses, for communication via email and via social media and for learners to be able to complete their school projects.

The project supported by the Department of Arts and Culture, which started in 2015, continues: research and workshops have been conducted with the youth and business people of Sutherland. The next phase will be assisting the youth to start their own businesses.

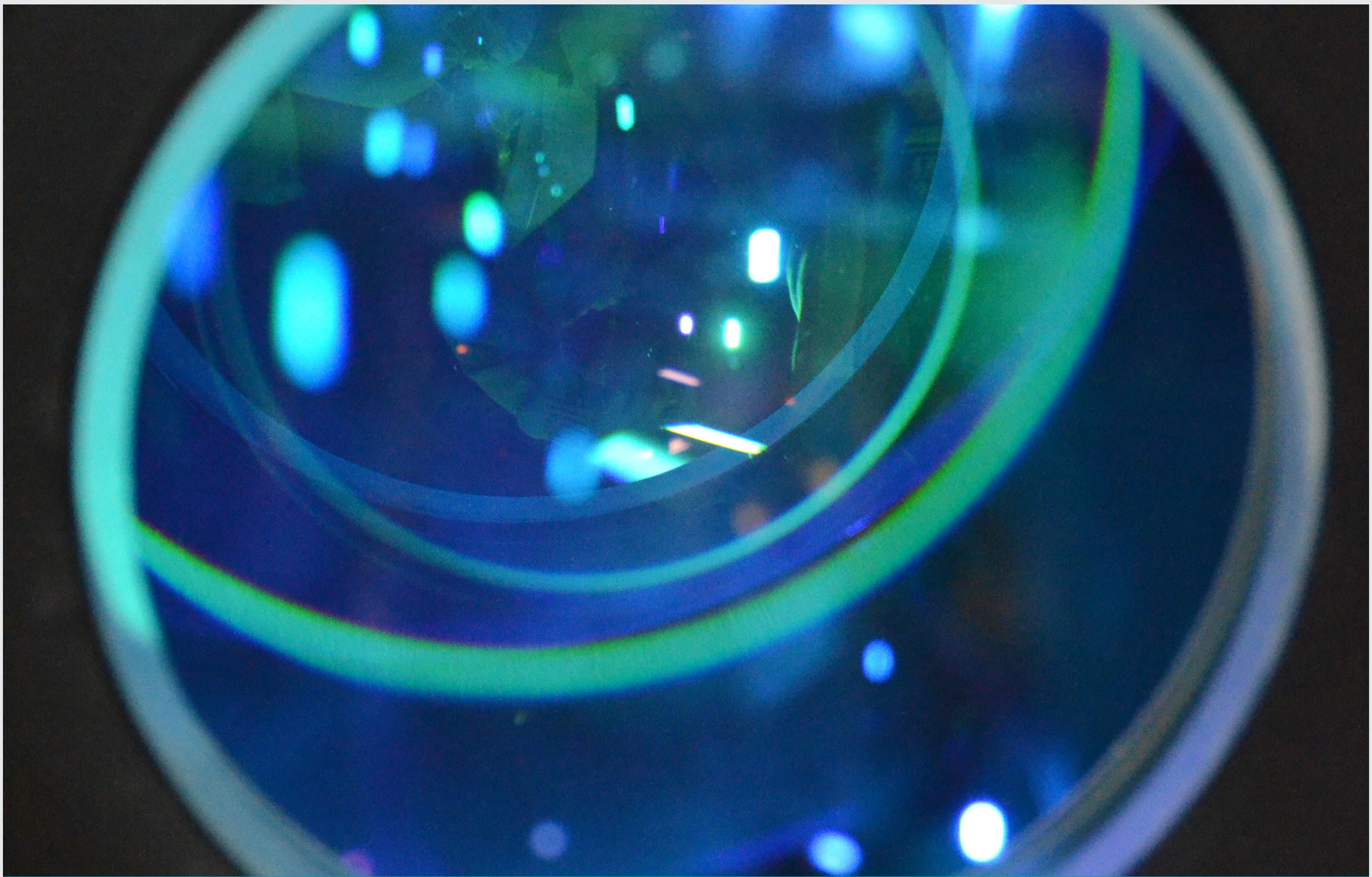
The Minister of Economic Development, Mr Ebrahim Patel, visited Sutherland; his department will initiate new programmes for the people of Sutherland.

SALT Partners

We would like to thank our SALT partners for all their assistance in the execution of education and outreach programmes: Prof. Phil Charles from Southampton University for the assistance with fund-raising for outreach from various sources; Prof. Brian Chaboyer from Dartmouth College for involving his students in outreach activities in Cape Town; Prof. Eric Wilcots and his team from the University of Wisconsin-Madison for supporting and collaborating in education and outreach activities; Prof. Mike Shara from the American Museum of Natural History for advice on improvements for the Visitor Centre and also for guidance in the training of tour guides. We also thank the members of the SALT board for giving presentations and talking to learners in Mowbray and Phillipi during the last board meeting in November 2017. Finally we wish to thank SAAO's director Prof. Ted Williams for all his support for the SCBP programme.

OUTREACH & EDUCATION:

ACTIVITIES BY OTHER INSTITUTIONS



DARTMOUTH COLLEGE

Dartmouth Professors Brian Chaboyer and John Thorstensen brought a group of 16 students (14 undergraduates and 2 graduates) to South Africa for a 10-week academic term starting in January 2017. The Dartmouth group was hosted by the University of Cape Town and SAAO during their visit. The students participated in the National Astrophysics and Space Science Programme (NASSP) summer school at SAAO, learning about South African astronomy and interacting with their peers from South Africa. A highlight for the group was a two-week observing run at Sutherland, where the students used the 1.9-m and 1.0-m telescopes and had an extended visit to SALT. In addition to their academic course work while in Cape Town, the Dartmouth students participated in several events run by the outreach group at SAAO, including giving presentations at local schools and a public observing event at the Waterfront.

Dartmouth students visiting SALT.

One of the Dartmouth students teaches young learners at a school in kwa Langa about the scale of the solar system.

DEEPER, WIDER, FASTER – A CITIZEN SCIENCE PROGRAMME

The group working with Jeff Cooke at Swinburne University of Technology is partnered in the 'Deeper, Wider, Faster' (DWF) programme which is one of the largest collaborative science programmes in the world. Its aim is to identify fast transients minutes after the light hits the telescopes; exotic events like fast radio bursts and bursts associated with gravitational waves are called 'fast'. The data is immediately processed and analysed. The need to identify and classify these transients as quickly as possible has led to a burgeoning citizen science programme: candidate identification is done with software and sophisticated data visualisation and sonification technology and has enabled students, young aspiring scientists, and the general public to join in the real-time discovery of these fast transients. Once identified, candidates are observed with telescopes like SALT, which is one of the science drivers for this programme.

Jeff and his team have been developing the sonification techniques (that is, converting data into sound) used for this project to enhance and improve the efficiency and productivity of analysing large or complex data sets. As such, vision-impaired and blind people with a passion for science can now join in and help find new and exciting objects in the sky.

OUTREACH & EDUCATION:

VISITING SALT

OFFICIAL DELEGATIONS

In 2017, various national and international delegates visited SALT at Sutherland.


SALT Board members visiting the control room.

30 – 31 January
SALT Data Workshop delegates

Group of 10 people

14 – 15 March
Swedish Delegation

Prof. Garrelt Mellema
Dr. Matthew Hayes
Prof. Cathy Horellou
Emma Olsson
Prof. Nik Piskunov

4 – 5 November
NAOC Delegation

Prof. Jun Yan, Director General of the National Astronomical Observatories, Chinese Academy of Sciences (NOAC)
Prof. Yanchun Liang, Director of the International Cooperation Dept.
Prof. Xuelei Chen
Prof. Yihuan Yan, Director of the Solar Physics Division, NAOC
Prof. Chenzhou Cui
Prof. Yanxia Zhang
Prof. Yinzhe Ma

10 – 12 November
SALT Board

4 – 5 December
Swiss Delegation

Ambassador Helene Budliger Artieda
Mr. Alex Artieda
Mr. Thomas Hippele, President SwissCham
Mrs. Franziska Saager, SwissCham member, owner of Eikendal Wines
Mrs. Daniela Maurer

9 – 10 December,
29th Texas Symposium on Relativistic Astrophysics

Dr. Piret Kuus, Head of the Laboratory of Theoretical Physics, University of Tartu, Estonia
Phillip Helbig, Germany
Dr. Guillaume Belanger, European Space Agency, Spain (and his wife)
Mr Dennis Alp, KTH Royal Institute of Technology, Sweden

MEDIA VISITS TO SALT

February 2017: Rosso Fuoco Film

SALT and the community of Sutherland stars in a film called "Star Stuff", directed and produced by the Italian Filmmaker Milad Tangshir. The documentary charts a journey of four observatories on four continents (Hawaii, Chile, South Africa and the Canary Islands), searching for humanity's place in the Universe. "Nearby those observatories, astonishing humans live in remote villages. The film penetrates into their daily life and explores their dreams and passions. Four places so distant to one another, but inhabited by humans who share the same vulnerability and longing for life", says Milad Tangshir. The film ulimately seeks to address various questions which include the impact of astronomy as a discipline on our world views: To what extent can astronomy contribute towards development of a better world?

The film features old members of the Sutherland community and some members of staff of the SAAO. The stories told by the members of the community reflect the wickedness of South Africa's apartheid history but, on a positive note, also show how the Observatory and the existence of SALT has had a positive impact on their personal lives and the community. Later in the evening, after the interviews, the crew visited SALT for images and a sweep of the work at night. Afterwards they took a time-lapse of the skies to showcase the magnitude of stars in relation to human insignificance.

The film will be released in late 2018.

February 2017: Xenius, Arte TV

Arte is a German/French public service TV that provides cultural programmes to the European community. Their daily programme Xenius is a science magazine that breaks down interesting scientific topics so that everyone can understand and appreciate them. In June 2017 they had a South African week broadcast with one episode dedicated to the topic 'The Milky Way'. About 11 minutes of the half-hour long transmission was about SALT: how a large telescope works and how it can help to improve the understanding of our Galaxy. The crew visited SALT in February for one day and filmed on the plateau with SALT in the background, inside the dome showing the mirror, interviewed David Buckley (SAAO) outside as well as in the control room and Anja Schröder (SAAO/SALT) at the visitors telescopes for some night impressions.

May 2017: Fuzzy Head Film

The film material has been used for the production of a Taster Tape that was presented to the BBC, SABC and other media outlets in June 2017. The idea was to make a short film using the images shot at SALT, then enter the film in South African and international festivals. The target audience is a non-specialist audience with an interest in astronomy.

CORPORATE GOVERNANCE

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The affairs of the SALT Foundation are regulated by the Shareholders' Agreement, signed at the formation of the Company. In terms of this agreement, the Company is controlled by a Board of Directors comprising two members from the National Research Foundation and one member from each of the remaining partner institutions. The Directors are elected at the Annual General Meeting of the Company and serve for a period of three years, following which they may be re-elected. All Board members are independent, Non-Executive Directors.

In this reporting period, the Board comprised of the following members:

Prof. Michael Shara (Chair)
American Museum of Natural History, USA

Prof. Gerald Cecil
University of North Carolina at Chapel Hill, USA

Prof. Brian Chaboyer
Dartmouth College, USA

Prof. Phil Charles
United Kingdom SALT Consortium, UK

Prof. Nithaya Chetty
(Resigned 30/06/2017)
National Research Foundation, South Africa

Dr. Lisa Crause
National Research Foundation, South Africa

Prof. John P. Hughes
Rutgers University, USA

Dr. Molapo Qhobela
(Appointed 09/11/2017)
National Research Foundation, South Africa

Prof. Somak Raychaudhury
Inter-University Centre for Astronomy & Astrophysics, India

Prof. Marek Sarna
Nicolaus Copernicus Astronomical Centre, Poland

Prof. Eric Wilcots
University of Wisconsin-Madison, USA

Other officers of the Company include Mrs. Lizette Labuschagne (Chief Financial Officer, Company Secretary and Business Manager).

The Board meets twice a year, usually in May and November. The SAAO Director and senior staff involved in the operation of the telescope also attend the Board meetings.

Operations contract

In terms of the Shareholder's Agreement, SALT is operated on behalf of the SALT Foundation by the SAAO and managed by the SAAO Director, Prof. Ted Williams. With the exception of Mrs. Lizette Labuschagne, the staff who carry out the day-to-day operational activities are SAAO employees. Engineering operations are managed by the SALT Operations Manager, Mr. Chris Coetzee, while Dr. Petri Väisänen heads the Astronomy Operations team. The operations plan and budget are presented by the SAAO Director at the November Board meeting for the following financial year.

The Board Executive Committee (BEC)

The Board has delegated authority to the Board Executive Committee (BEC) to manage the Company during the period between Board meetings. The BEC meets every 6 weeks and receives reports on the operations and development of the telescope from the SAAO Director and other senior staff with the relevant responsibilities. The BEC comprises 4 Board members. In this reporting period, they were: Prof. Mike Shara (Chair), Prof. Brian Chaboyer, Prof. Eric Wilcots and Prof. Phil Charles.

The Finance and Audit Committee (FAC)

Although the full Board takes responsibility for the Annual Financial Statements of the Company, the Board has appointed a Finance and Audit Committee (FAC) to interrogate the management of the financial affairs of the Company at a detailed level. This committee meets at least twice a year, shortly before Board meetings, and presents a report at the Board meeting. In this reporting period, the members of the FAC were: Prof. E. Wilcots (Chair), Prof. G. Bromage and Prof. J. Hughes.

Technical Operations Team 2017

Chris Coetzee (Head)

Deon Bester*
Janus Brink
Keith Browne
Lisa Crause
Willa de Water
Timothy Fransman
Hitesh Gajjar*
Denville Gibbons
Johan Hendricks
Stephen Hulme
Nicolaas Jacobs
Anthony Koeslag
Wouter Lochner*
Jonathan Love
Deneys Maartens
Thabelo Makananise
Adelaide Malan
John Menzies*
Vic Moore*
Paul Rabe
Etienne Simon
Ockert Strydom
Raoul van den Berg*
Eben Wiid

Astronomy Operations Team 2017

Petri Väisänen (Head)

David Buckley*
Steve Crawford
Éric Depagne
Christian Hettlage
Alexei Kniazev
Thea Koen
Marissa Kotze
Rudi Kuhn
Nhlavutelo Macebele
Fred Marang*
Anelisiwe Mayekiso*
Brent Miszalski
Encarni Romero-Colmenero
Anja Schröder*
Rosalind Skelton
Veronica van Wyk

Corporate Governance Team 2017

Lizette Labuschagne
Surayda Moosa

* part-time and/or part of the year

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GLOSSARY OF ACRONYMS

AAT	Anglo-Australian Telescope
ADAF	advection dominated accretion flow
AGN	active galactic nucleus
ALMA	Atacama Large Millimeter Array
AMNH	American Museum of Natural History
ANU	Australian National University
ASASSN	All Sky Automated Survey for SuperNovae
BCG	brightest cluster galaxy
BCU	blazar candidates of uncertain type
BEC	board executive committee
BH	black hole
BLR	broad line region
BVIT	Berkeley Visible Image Tube camera
CAMK	Nicolaus Copernicus Astronomical Center
CCD	charge-coupled device
CFO	chief financial officer
CHILES	COSMOS HI Large Extragalactic Survey
COSMOS	COSMOlogical evolution Survey
CRISP	Calibration Ruler for Increased Spectrograph Precision
CTA	Cherenkov Telescope Array
DC	Dartmouth College
DDS	data distribution service
DDT	director's discretionary time
dSph	dwarf spheroidal
DST	Department of Science and Technology
DWF	deeper, wider, faster
E-ELT	European Extremely Large Telescope
ESO	European Southern Observatories
FAC	finance & audit committee
FIF	fibre instrument feed
FP	Fabry–Pérot
FSRQ	flat spectrum radio quasar
FTS	Fourier transform spectrometer
FWHM	full width half maximum
GC	globular cluster
GCN	Gamma-ray Coordinates Network
GRBi	γ-ray binaries
H.E.S.S.	High Energy Stereoscopic System
HET	Hobby-Eberly Telescope
HR	high-resolution (Fabry–Pérot)
HRS	high-resolution spectrograph
HS	high-stability (Fabry–Pérot)
HST	Hubble Space Telescope
IFU	integral field unit
INAF	National Institute of Astrophysics
IO	input/output
ISDEC	IUCAA SIDECAR Drive Electronics Controller
ISI	international scientific indexing
ISM	interstellar medium
IUCAA	Inter-University Centre for Astronomy & Astrophysics
KAT	Karoo Array Telescope
LADUMA	Looking At the Distant Universe with the MeerKAT Array
LIGO	Laser Interferometer Gravitational Wave Observatory
LIRG	luminous infrared galaxy
LOFAR	LOw Frequency ARray
LRG	luminous red galaxy
LSP	large science programme
LSST	Large Synoptic Survey Telescope
MASTER	Mobile Astronomical System of the TElescope-Robots Network

MOS	multi-object spectrograph
MR	medium resolution
MUSSES	MUlti-band Subaru Survey for Early-phase SNe Ia
NASSP	National Astrophysics and Space Science Programme
NIR	near-infrared
NLR	narrow line region
NRF	National Research Foundation
NTT	New Technology Telescope
NuSTAR	Nuclear Spectroscopic Telescope ARray
NWU	North-West University
PAS	Polish Academy of Sciences
PC	personal computer
PI	principal investigator
PIPT	Principal Investigator Proposal Tool
POL	Poland
PRV	precise radial velocities
PWFS	pyramid wavefront sensor
PXI	PCI eXtensions for Instrumentation
QSO	quasi-stellar object
RINGS	RSS Imaging spectroscopy Nearby Galaxies Survey
RSA	Republic of South Africa
RSS	Robert Stobie Spectrograph
RU	Rutgers University
SA	South Africa
SAAO	South African Astronomical Observatory
SAASTA	South African Agency for Science and Technology Advancement
SAEON	South African Earth Observation Network
SALT	Southern African Large Telescope
SAMS	SALT array management system (i.e., active mirror alignment system)
SARAO	South African Radio Astronomy Observatory
SASTAC	South African SALT time allocation committee
SCBP	SALT collateral benefits programme
SDB	SALT science database
SDSS	Sloan digital sky survey
SED	spectral energy distribution
SKA	Square Kilometre Array
SMBH	supermassive black hole
SMC	Small Magellanic Cloud
SN	supernova
SNR	supernova remnant
SSWG	SALT science working group
TESS	Transiting Exoplanet Survey Satellite
ToO	target of opportunity
UCLan	University of Central Lancashire
UCLES	University College London Echelle Spectrograph
UCT	University of Cape Town
UKSC	United Kingdom SALT Consortium
ULIRG	ultra luminous infrared galaxy
UNC	University of North Carolina – Chapel Hill
UNISA	UNIversity of South Africa
UW	University of Wisconsin-Madison
UWC	University of the Western Cape
VBT	Vainu Bappu Telescope
VHE	very high energy
VLBI	very long baseline interferometry
VLT	Very Large Telescope
WebDAV	Web Distributed Authoring and Versioning
WISE	Wide-field Infrared Survey Explorer
XRB	X-ray binary
ZMQ	ZeroMQ

The SALT consortium is seeking an additional 10%-level partner (~$8.8M) to support significant second-generation instrumentation development.

Interested parties should contact the chair of the SALT Board of Directors, Michael Shara*.

Editor

Anja Schröder, SAAO/SALT

Design & typesetting

Madi van Schalkwyk

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Authors (unless denoted)

Janus Brink
Chris Coetzee
Lisa Crause
Steve Crawford
Éric Depagne
Anthony Koeslag
Lizette Labuschagne
Deneys Maartens
Sivuyile Manxoyi
Encarni Romero-Colmenero
Anja Schröder
Petri Väisänen
Eric Wilcots

Image credits

Janus Brink
Brian Chaboyer
Lisa Crause
Chantal Fourie
Anthony Koeslag
Willie Koorts
Sivuyile Manxoyi
Anja Schröder
Hester Schutte

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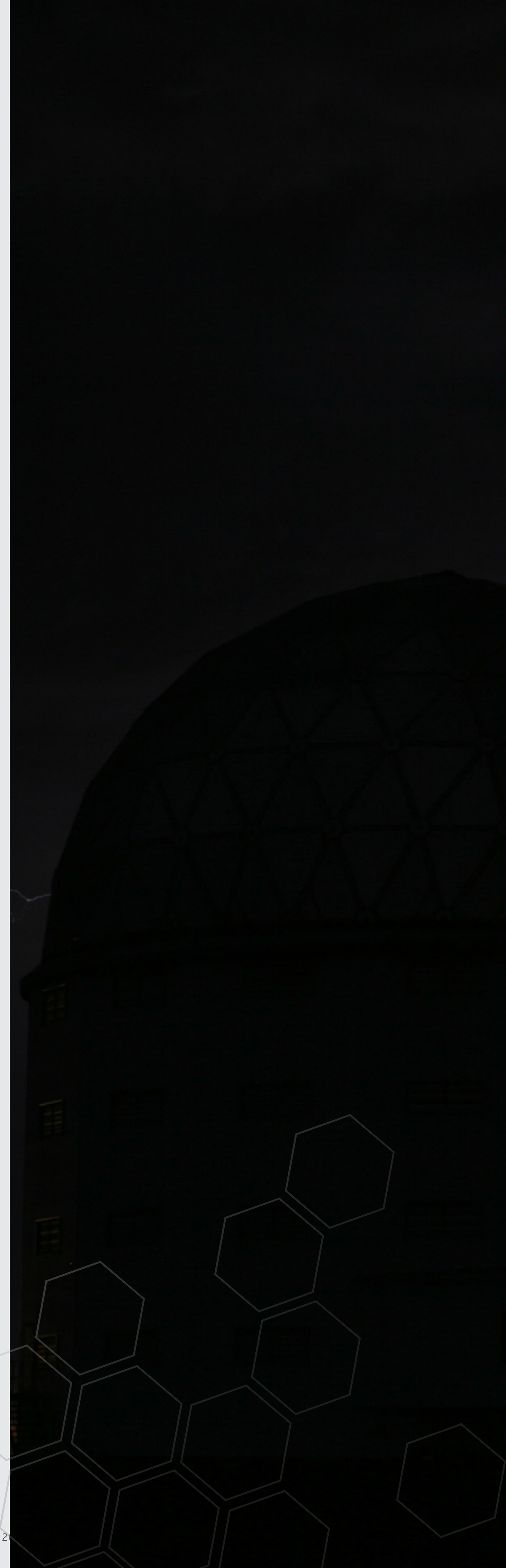
* mshara@amnh.org



www.salt.ac.za/contact

CAPE TOWN

PO Box 9, Observatory, 7935, South Africa

Phone : +27 (0)21 447 0025

Email : salt@salt.ac.za

SUTHERLAND

Old Fraserburg Road, Sutherland, 6920

Phone : +27 (0)23 571 1205

Fax: +27 (0)23 571 2456